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EVENT RECORDERS FOR RAIL RAPID TRANSIT SYSTEMS

JUNE 1998

Federal Transit Administration

Office of Research, Demonstration and Innovation

NOTICE

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16. Abstract

The *Federal Transit Administration*, stimulated in part by a recommendation of the *National Transportation Safety Board*, is exploring the effectiveness and efficiency of using event recorders on rapid rail cars in recognition of NTSB's strong emphasis on the value of data derived from event recorders in rail accident investigations. This study presents and analyzes data, defines various aspects of using accident/incident event recorders, performs a cost, feasibility and benefit analysis, and identifies the technical requirements for these devices in rapid rail transit. Data from actual experience is used where available.

Event recorders, defined in the broadest sense, are valuable for monitoring and diagnosis of equipment and system problems, for engineering and administrative management of system operations and system performance, as well as for accident and incident analysis. Several usable technologies are available. Costs of installing event recorders are likely to be different for older transit cars compared with those recently built. The lowest cost and least difficulty is incurred when these systems are installed during the construction of new cars. The assessment concludes that the greatest value accrues from a combination of recorder functions for operations, maintenance and diagnostics integrated with those needed for accident/incident investigation.

The safety record in transit operations is good when compared to most other transportation modes, and it can be argued that accident investigation is often simpler for transit than, for example, for aviation and maritime applications. At the same time, the capture of complete, timely and accurate information for investigations, which recorders can provide, is highly beneficial.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gr)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32) (5/9)]°F = y°C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, sq^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)

1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)

1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5)y + 32]°C = x°F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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EXECUTIVE SUMMARY AND PRIMARY FINDINGS

The *Federal Transit Administration (FTA)*, stimulated in part by a recommendation of the *National Transportation Safety Board (NTSB)*, is exploring the effectiveness and efficiency of using event recorders on rapid rail cars in recognition of NTSB's strong emphasis on the need for and value of data derived from event recorders in rail accident investigations. The *Federal Aviation Administration (FAA)* has long required carriage of data and voice recorders on transport aircraft and has recently promulgated a requirement for more capable systems. While aviation crash and voice recorders initially were used only for accident investigation, they are now increasingly used for many other purposes, such as monitoring of equipment and system performance.

Over the past two decades, the transit industry has been introducing advanced technologies for a variety of functions. Most vehicle systems are now controlled by embedded microprocessors, making status and diagnostic information readily available. Centralized on-board Monitoring and Diagnostic (M&D) systems are becoming more common in procurements of new cars and major overhauls. Interest is high in event recorders, either as part of an M&D system or as stand-alone accident investigation tools.

There are a number of coordination and standardization efforts under way through the *Institute of Electrical and Electronics Engineers (IEEE)*, the *Transportation Research Board (TRB)* and the *American Public Transit Association (APTA)* to define minimum and optimum requirements for recorder systems. Hardening of the recorders and finding the optimum location on the vehicle for recorders intended for investigation of accidents and incidents are important, and standards are being developed.

Ninety percent of all locomotives under the jurisdiction of the *Federal Railroad Administration* are equipped with event recorders. These event recorders are usually built-in for new locomotives. The technical differences between railroad locomotive application and transit application are centered on the fact that the propulsion and control of propulsion, braking and other functions are centralized for locomotives and may be distributed among cars in rail transit operations. Another difference between transit applications and many railroad applications is the frequency of interactions between passengers and doors.

In considering requirements for accident/incident recorders in rail rapid transit, it is important to recognize that such recorders do not directly *prevent* accidents; they only provide information that may help in understanding accident causes and event sequences, and thus ultimately help prevent *future* incidents and accidents.

Maintenance and diagnostic monitoring equipment is likely to improve service availability by warning of impending failures (trend analysis) or aiding in locating existing faults. This, in turn, improves the productivity of maintenance activities and can reduce maintenance costs.

A variety of usable technologies are available to serve any of several approaches to the implementation of recorders. Technology clearly is not a limitation. It also seems clear that, while transit agencies may choose to use separate devices for event recording for accident/incident investigation and for those used for operation and maintenance, engineering, diagnosis and administrative management, many of the needed data elements are identical or overlap. There would appear to be significant advantages in terms of cost and operational benefits from combining the two sets of functions in a *single integrated* system.

Even more than the cost of the recorders themselves, an important consideration is the cost and difficulty of installing needed sensors and cabling. These costs are likely to be significantly higher for older transit cars than for those recently built, with the lowest cost and least difficulty when the systems are installed during the construction of new cars.

The installation (particularly retrofit) of even a minimum capability recorder imposes an economic burden. However, if a modest maintenance and diagnostic benefit is recognized, the burden should not be heavy for new or recently-built cars, but would be more problematic for older cars without any provisions for this equipment.

As in all transportation modes, data protection issues need to be resolved. A key impediment to the implementation of event recorders is associated with the protection of data from use for other than safety and operational improvement purposes and from tampering. Several transit officials noted that some train and transit operators tend to view event recorders with suspicion, with some concluding that the purpose of an event recorder, especially in an accident, is to determine whether the cause of the accident was human error or equipment failure. Similar concerns were prominent for many years among aviation officials and representatives of pilot organizations, although in recent years accommodations have been made to permit use of valuable data without invading privacy.

The safety record of rail transit operations is generally excellent when compared to most other transportation modes, and it can be argued that accident investigation is simpler for transit than, for example, for aviation and maritime applications. At the same time, capturing accurate and timely information is highly beneficial in any accident or incident investigation. Fully knowing the causes of accidents permits changes to be made to equipment, maintenance procedures, operating procedures and/or training to minimize the chance of future accidents.

Pursuing a goal of zero accidents is a shared responsibility of government, industry, and labor organizations. Government and industry approaches to safety must be *proactive* and focus on *anticipating safety hazards and preventing accidents.*

Primary Findings

- The findings from this effort indicate that the benefits from use of event recorders are likely to outweigh the costs, even when taking into consideration the difficulties of retrofitting older rail cars.

- Recorders can bring an integrated process to the capture, processing, and management of data needed to enhance rail safety and maintenance operations. Implementation of enhanced capability recorders (capable of recording more information than the minimum required for accident investigation) would be more cost-effective than basic event recorders, since they are more likely to improve operations and maintenance productivity.

- A requirement to carry at least a minimum capability recorder on newly purchased cars, while imposing an economic burden, would not be prohibitive, especially since a part of the cost can be offset against maintenance and diagnostic benefits. Assuming a very modest maintenance and diagnostic benefit, the cost burden would not be heavy for cars of recent vintage, but would be more problematic for older cars. As the maintenance benefit increases, the justification for retrofitting older cars increases.

- While the immediate safety benefits may not be readily apparent, recorders will enable transit operators to capture valuable performance data, predict trends and consider modifications before problems become widespread, and will enable more effective accident investigation. Event recorders do not directly prevent accidents; they are investigative tools when accidents or incidents occur, and performance trend data can be used to prevent future difficulties.

- Although most rail transit officials recognize the potential for improving safety and operations through event recorders, data protection issues, and the protection of data from use for other than safety and operational improvement purposes need to be considered.

RECOMMENDED MINIMUM DATA

The following is a summary of the recommended minimum data which should be captured by event recorders for rail transit operations:

1	Time (Y:M:D; HH:MM:SS)* relative to a defined standard	8	Actual speed
2	Master Controller position (propulsion, coast, braking, deadman)	9	Location (exact or relative to nearest station)
3	All other braking commands	10	Active cab
4	Brake pipe pressure	11	Reverser position (direction)
5	Brake cylinder pressure	12	Cab signal, speed code or train control status
6	Dynamic braking enabled	13	Trainlined door status data
7	Actual propulsion (traction motor current/torque)	14	Bypass, cutout or override controls relative to any of the above

* (Year:Month:Day; Hour:Minutes:Seconds)

Event recorders, especially recorders which provide data for both accident investigation and maintenance & diagnostics, can bring an integrated technical solution to the acquisition and management of the data required to enhance rail safety and maintenance operations.

I INTRODUCTION

As a result of the January 6, 1996 fatal accident at the Washington Metropolitan Area Transit Authority's (WMATA) Shady Grove, Maryland Station, the National Transportation Safety Board (NTSB), *recommended that the Federal Transit Administration (FTA) explore the effectiveness and efficiency of using event recorders on rapid rail cars.* NTSB has repeatedly emphasized the need for and value of data derived from event recorders in its rail accident investigations.

In recent years, the rail transit industry has undertaken a number of programs to examine the feasibility of implementing these systems, and has efforts under way through the Institute of Electrical and Electronics Engineers (IEEE) to develop industry standards for their manufacture and use. As this report was being written, the first applications of event recorders to rail transit are in various stages of procurement. However, it should be noted that event recorders are not currently required by regulation for rapid rail (or rail transit) systems[1], as they are for railroad freight and passenger applications under the jurisdiction of the Federal Railroad Administration.

The primary purpose of this research study was to develop a technical report exploring the feasibility of using accident/incident event recorders in rail transit. Under this broad overall context, the key objectives of the Applied Techno-Management Systems (ATMS) task were:

- To gather information on event recorders used in various transportation industries;
- To determine the feasibility of the universal use of event recorders on rail transit cars;
- To identify passenger safety enhancements resulting from the correct identification of contributing causes of accidents;
- To identify the technical requirements for these devices; and
- To provide an exploratory cost/benefit assessment of accident/incident event recorders, including ancillary advantages such as combining the event recorders with an equipment condition monitoring system.

It is important to note at the outset that event recorders, as part of a functionally broader Monitoring and Diagnostic System, have important uses other than just accident investigation. They are also valuable for monitoring and diagnosis of equipment and system problems, and for engineering and administrative management of system operations and system performance.

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[1] **rail rapid** (heavy rail transit, rapid rail transit) - a transit system that generally serves one urban area, using high-speed, electrically powered passenger rail cars operating in trains in exclusive rights-of -way, without grade crossings (Chicago is an exception) and with high platforms. The tracks may be in underground tunnels, on elevated structures, in open cuts, at surface level, or any combination thereof. Some local terms used for rail rapid transit are *the elevated, the metro, the metropolitan railway, the rapid, the subway, the underground* - From *Urban Public Transportation Glossary,* Benita Gray, Editor, Transportation Research Board, National Research Council, 1989

As expected, there are major differences in the cost of installing event recorders in new, recently-built transit cars, and older cars, just as there are philosophical differences among transit agencies as to the uses that can or will be made of event recorder data. Several different installation scenarios are discussed in this study.

The work included an examination of available data on rail accidents and incidents and the toll these have taken in fatalities, injuries and equipment costs. An attempt was made to relate the numbers of incidents and accidents that have occurred in the past to other measures to provide some basis for validation of a requirement for recorders on rapid rail cars. Where possible, parallels have been drawn between transit system applications and application of recorders in railroads and aviation. The *Federal Aviation Administration* has long required carriage of data and voice recorders on transport aircraft, and has recently established a requirement for systems which record additional data. *The Federal Railroad Administration* requires the carriage of recorders on most locomotives, and like FAA, requires the recorder(s) to be operational as a condition for dispatch.

The report also presents a technical and management framework for implementation of event recorders, and discusses issues and constraints that need to be considered. Integral to this study is an assessment of potential costs and benefits of event recorders and monitoring and diagnostic systems. Lack of realistic data related to operations and maintenance costs, expected productivity and efficiency improvements, and quantification of potential benefits has been an impediment to conclusive cost/benefit analysis. However, data from actual experience was used when available.

In the course of preparing this report, ATMS staff held a series of meetings with selected staff of the American Public Transit Association (APTA), the Federal Railroad Administration (FRA), and the Washington Metropolitan Area Transit Authority (WMATA) and conducted numerous discussions with rail transit, operators, industry experts, and equipment suppliers.

II RATIONALE FOR THE USE OF EVENT RECORDERS

This section examines the existing regulatory environment, as well as the use and definitions of event recorders in the transportation industry, and discusses their potential value and utility in enhancing safety, improving efficiency, and reducing operations and maintenance (O&M) costs in qualitative terms. Some of the available statistical data on accidents and fatalities in various transport modes is examined in order to establish a rationale for the use of event recorders as a means of avoiding potential accidents. In this section, limited industry experience in using event recorders, separately or in combination with monitoring and diagnostic capabilities to improve the safety, reliability and efficiency of rail service, is reviewed.

2.1 The Regulatory Environment and Data Utilization for Safety

The Department of Transportation (DOT) has the statutory responsibility for the safe operation of the nation's transportation system. The responsibility is carried out directly by the *Federal Railroad Administration*, the *Coast Guard* and the *Federal Aviation Administration* who directly make rules for their transportation modes. The *Federal Transit Administration*'s responsibilities are similar to those of the other modes, but the administrative process is less direct. The role of the *Federal Transit Administration* is primarily to fund purchase of transit vehicles, equipment and facilities. Regulation of fixed guideway systems is now a state responsibility under recently-issued state safety oversight regulations 49 CFR. Part 659.

In the investigation of accidents and incidents, accurate, precise and complete information on all potentially pertinent factors leading to the accident or incident are the most powerful tools in the hands of the safety investigators. The recorders required to be carried on most commercial transport aircraft (the "black boxes") which record aircraft and flight data and cockpit and pilot voices (for a number of minutes) have proven to be highly valuable tools for the FAA, the *National Transportation Safety Board* (NTSB), and public and private agencies and experts which support NTSB in its investigations.

Starting in aviation with five data elements scribed onto metal foil (to help assure survival of the data) and a 30 minute endless-loop voice recorder in the cockpit, the capabilities and the amount of data taken has evolved so that far more data is now available. While in the early days of the use of such recordings, they were used only for accident investigation, the use of the data has slowly been extended to serve a number of more routine uses (performance trends, gradual problem development, etc.), as concerns about the possible misuse of the data in punitive actions against individuals abated. Only recently, the FAA increased the number of parameters to be recorded, by regulation, after lengthy consultations with industry.

Recorders carried on railroad locomotives similarly have value in the investigation of accidents and incidents. Recorders increasingly carried aboard long-distance trucks, initially intended for use by management, have become vital tools in accident investigation.

2.1.1 Utilization of Recorder Data in Accident and Incident Investigation

Retrieval of data from an accident or serious incident is an important priority for all who will be involved in the investigation. When found, data recorders (in aviation, both voice and data recorders) are turned over to the responsible officials of the National Transportation Safety Board (NTSB) for examination and safe-guarding.

NTSB usually exercises its responsibility for accident investigation by supervising the retrieval, data reduction, and analysis of the data obtained. NTSB, in this process, as in most phases of accident investigation, invites and utilizes responsible officials representing the agencies involved. It further uses experts from the builders and operators of the vehicles and their systems, as well as the manufacturers of the recorders and data gathering systems who have expertise in interpreting the data captured.

The extent of involvement of outside experts is of course dependent on the severity of the accident or incident, as well as the difficulty of ascertaining causes and other factors, but it is in the interest of all parties to gain the best perspective on accident causes and possible mitigation.

Accurate data on the key parameters which might shed light on the sequence of events in an accident have been found of immeasurable help in analyzing accidents and pinpointing causes. The continuity and relationships of various data elements, and especially the precise timing available from the recorders, are used by investigators as vital elements in the fact-finding process which is the heart of the accident investigation and the establishment of causes and responsibilities.

The data sets obtained from recorders perhaps have their greatest value because they are fully objective. In accident investigation, they are routinely used to buttress and confirm the testimony of witnesses and participants, because the recall even of eye witnesses may be flawed.

The objective data from voice recorders become an essential part of any legal or judicial proceedings which may arise out of the accident investigation. Unlike bystander or human witness recollections, the recorded data are usually beyond challenge.

The selection of the most important data parameters to be recorded will vary by mode of transportation, and is best accomplished with the proper use of this data by the modal agency, industry and NTSB experts. While virtually any data is potentially valuable (and sometimes crucial) to an investigation, limiting choices must be made. The work of IEEE (the Institute of Electrical and Electronics Engineers) supported by the Federal Transit Administration, the Transportation Research Board (TRB), as well as government and industry experts in developing a standard for the electrical interfaces is a highly valuable service in selecting the information elements for accident/incident recorders.

2.2 Key Definitions

It is important to define Event Recorders and Monitoring and Diagnostic Systems as part of the overall framework for reviewing their potential utility. Definitions are also important in specifying the purpose and use of event recorders, as well as in identifying the potential costs and benefits of using them in a rapid rail transit environment.

2.2.1 Event Recorder Definitions

In draft IEEE Standards being developed by the Vehicular Technology Society's Rail Transit Vehicle Interface Standards Committee[1], an **Event Recorder** is defined as an

> *". . . on-board device/system with crash-worthy memory which records data to support accident/incident analysis"*

In the draft IEEE Standards P1482 and P1482.1, **Event Recorder** signals are described as a subset of signals available to a centralized rail vehicle **Monitoring and Diagnostic (M&D) System.** The IEEE Working Group (WG3) developed specifications for event recorders using the requirements of the Federal Railroad Administration as a starting point, interpreting and extrapolating them to rapid rail transit applications. The draft Standards list the required signals in detail.

An **FRA Event Recorder**, as defined in CFR 49 Section 229.5(g), is a device

> *". . . that monitors and records data on train speed, direction of motion, time, distance, throttle position, brake applications and operations (including train brake, independent brake, and, if so equipped dynamic brake applications and operations) and, where the locomotive is so equipped, cab signal aspect(s) over the most recent 48 hours of operation . . ."*

The latter definition is broad, but it lacks accident survival requirements. A railroad industry group is working to refine the definitions and add accident survival criteria.

For accident investigation, the *critical* time is just before and immediately after the accident or incident. However, operating time periods long enough to establish a gradual failure buildup would be valuable to trace the events leading to some accidents and incidents. In railroad accidents, the locomotive in which the event recorder is installed, if still operational, might be the only one available to assist in clearing the rails for other traffic, so the CFR requires that 48 hours of data be preserved to prevent overwrite of the accident data. Rail transit operations are similar to railroad applications in that the event recorders may begin recording subsequent non-accident data when power is restored after an accident. Some rail transit operations (such as automated or driverless) may not be interrupted at all when an incident of interest occurs. Protecting data from being overwritten with subsequent data must be a consideration. Twenty-four to fourty-eight hours is considered adequate by industry groups, depending on operating procedures and practices.

For many uses, the enhanced **Monitoring and Diagnostic (M&D) System** described in draft IEEE Standard P1482 would provide for more costs and benefits than a recorder intended primarily (perhaps exclusively) for accident and incident analysis (described in draft IEEE Standard P1482.1).

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[1] IEEE official website: http://stdsbbs.ieee.org/groups/railtransit/index.html
Committee meeting and Working Group general information: http://www.TSD.ORG/wg3.htm

2.2.2 Types of Recorders

There appear to be three primary functions for which recorders may be used in rapid rail transit vehicles:

2.2.2.1 Basic Event Recorders

Basic Event Recorders for *accident and incident analysis* by transit management and government investigators, primarily intended for after-the-fact collection of data needed for analysis of accidents or incidents.

2.2.2.2 Enhanced Event Recorders

Recorders for basic event recorder functions as well as for recording performance of various functions as to sequence, frequency, adequacy, effectiveness, and history for downloading and use by maintenance personnel for *diagnosis* and/or for engineering and management to monitor and maintain records of *system performance.*

2.2.2.3 Monitoring & Diagnostic Recorders

Recorders incorporating functions of basic and enhanced event recorders which may also be used for *monitoring* performance and helping in *diagnosis* of problems. The data may be used in real time to serve the operator (with appropriate displays), as well as for gathering historical performance data. This type of recorder may also record a larger number of functions over a greater range of frequencies than basic or enhanced event recorders, with more options for user control over what is monitored and how it is presented.

Other selected definitions are summarized in Appendix 1.

2.3 Transportation Industry Experience with Event Recorders

Data and voice recorders are widely used in the aviation industry and are mandated by the Federal Aviation Administration for all transport aircraft. While aviation crash and voice recorders initially were used only for accident investigation, they are now increasingly used for other purposes. As this report was being written, the first applications of event recorders in rail transit are in various stages of procurement and initial service.

The Rail Safety Improvement Act of 1988 requires that event recorders be installed on passenger and freight trains operating at speeds of 30 miles per hour or more, with a consist of more than 50 cars, or more than 4000 feet in length. The FRA enforces the use of event recorders in the railroad industry. The FRA event recorder requirements apply to self-propelled equipment, such as electric or diesel "multiple units" and unpowered cab cars as if they were locomotives. Among the FRA-regulated rail modes, the Electric Multiple Unit (EMU) car technology is most like the heavy rail car technology used in rail transit applications not under FRA jurisdiction. Because of the technical differences between locomotives and self-propelled cards such as EMUs, commuter railroads have experienced difficulty in obtaining and installing event recorders on their EMU fleets. The FRA has been working with the commuter railroads in their efforts to implement event recorder technology, granting waivers and time extensions as necessary.

The efforts of commuter railroads to comply with the FRA event recorder regulations are of interest for this report, because of the similarities between EMU and rail transit vehicle technologies. The experience of the commuter railroads may be directly usable by transit agencies to help avoid expensive and time-consuming problems.

The transition of event recorder technology to rail transit can be directly compared to the application of event recorders to commuter rail Electric Multiple Unit (EMU) cars. The technical challenges of event recorder installation in rail transit and EMUs include capturing signals from the propulsion, braking and control of propulsion, braking, and other functions from physical locations which may be distributed among two or more permanently (or semi-permanently) coupled cars. Another similarity between EMUs and rail transit vehicles (and a major difference from locomotives on freight railroads) is the importance (especially in accidents) of interactions between passengers and doors, as evidenced by interlocks between doors and propulsion. The FRA has not yet addressed door signals in event recorder regulations.

There are a number of EMU car event recorder applications in service. These applications, especially those retrofitted to older EMU cars, have not been achieved easily for the commuter railroads. Captured below are some generalizations from commuter railroad industry experience to date with EMU applications.

- Most commuter railroads go through similar processes when preparing to install new technology such as event recorders. They define their needs in a general way, obtain units for test, refine their technical specification, then order and install larger quantities. Unfortunately, it has not been unusual for an agency to completely replace the first set of event recorder equipment procured with event recorders better suited to their needs. A majority of the first installations on EMU cars have already been replaced.

- Event recorders are in revenue service on the majority of EMU cars, collecting data and being used to assist operators with investigations of accidents. Most of the balance of the EMU car fleets in the country had procurements underway. Event recorders are now a standard part of new EMU procurements, as they are for locomotives.

- Event recorders are commonly used by commuter railroad maintenance staff to assist with troubleshooting that was not possible before this equipment was installed. There are cases where an agency has had trouble with event recorder testing or procurement, but the maintenance staff has been able to use the information captured by the units even before the recorders were commissioned for their intended use. A frequent use has been to determine the cause of wheel flats.

- Train operating crews may tend to view event recorders with suspicion. Some believe that the purpose of an event recorder, especially in an accident, is to determine whether the cause of the accident was human error or equipment failure. This perception makes the event recorder a potential target for tampering.

- Time and date stamping has evolved, and attention is being paid to consistent date and time stamps of data. In some early accidents, the event recorders added to confusion regarding the exact time of an accident. Railroads and transit agencies now decide whether they want to time stamp with local, daylight saving time, corrected time, or with a constant standard time such as Greenwich Mean Time. It is desirable for the time stamp to be consistent with time stamps of other data in fault logs for the various systems so that, if the logs survive, their data can support the accident investigation.

- As with most safety regulations, each accident has led to refinements in technical requirements and specifications for recorders and their installation. Mechanical requirements are under consideration to assure that the memory units survive the accident for whose investigation their data is needed. An unfortunate example was a passenger rail crash in which the event recorder data was ruined by submersion in water. Magnetic tape has largely been replaced by non-volatile memory and immersion requirements are becoming part of standard procurement requirements.

Several commuter railroads have experienced difficulties procuring and installing event recorders on EMU cars. The difficulties fall into several general categories that are directly applicable also to rail transit:

- defining signals, based on the FRA list
- implementing the interface between the EMU and the event recorder
- handling the data after collection.

2.3.1 Defining Signals, Based on the FRA List

The CFR lists signals which must be captured. The rail industry has struggled with interpretation of that list so it can decide how (and where) best to connect the event recorder channels to the car. The difficulty in making decisions is due to interpreting what was intended by the FRA, and applying it to the specific target vehicle.

The Code of Federal Regulations (CFR) lists required signals as "train speed, direction of motion, time, distance, throttle position, brake applications and operations (including train brake, independent brake, . . . dynamic brake applications and operations) and, . . . cab signal aspects." These eight signals have numerous components which make the basic number of inputs to a black box far more than eight. For instance, in May 1995, the rule clarified "throttle position" to mean Master Controller position in EMU cars (perhaps five inputs).

Railroads and transit agencies have interpreted the rule in different ways. The IEEE working group of industry experts has agreed that the signals to be captured should include the Command or Request for power or braking and the result or vehicle response to that request.

Once the specific signals appropriate to a specific car type are determined, a source for the signals must be located, must provide the information desired, and must be accessible and as close as possible to the proposed physical location of the event recorder. In some cars, many of the desired signals can be found near the propulsion and/or braking controls, depending on how recently the cars were deployed.

Some railroads that began using signals from their cab signal equipment to meet, or partially meet, the CFR requirements (with the balance of the signals captured in a different box) have since retrofitted their fleets with standard recorders to allow uniform recording of a standard set of signals. Others continue to split their recording of signals among different physical locations to reduce the expense of complying with the rule.

2.3.2 Implementing the Interface Between the Car and the Event Recorder

When performing any retrofit on existing cars, difficulties can result from lack of space for new cables and from lack of precise documentation of the final, as-deployed design of the car wiring.

Experience with adding event recorders to EMU cars depends to some degree on how old the technology of the EMU is, and whether or not signal conditioning has been added to allow cab signal updates or other advanced technology upgrades. Older technologies are more tolerant than newer ones of the noise, voltage spikes, and electrical transients present on most rail lines. Event recorders tend to employ newer technologies, and require protection from the harsh non-digital environment of older cars. A side benefit of adding event recorders to old cars can be that other car systems (existing or recent) benefit from the signal conditioning added to protect the event recorders.

Some railroads found that attempting to use motor current was not a practical method of recording power and brake status due to problems conditioning the signal for use by digital recording devices. However, others have found that with proper protection such use of motor current can be accurate.

New technology has provided its own pitfalls, especially for organizations unfamiliar with management of high tech procurements. Because each installation is, at least to some degree, a custom design, software development requires review and oversight that railroads and transit agencies are not necessarily prepared to provide. There have been instances of software "bugs" that interfered with event recorder performance and eroded the confidence of the operating agency in advanced technology generally and their event recorders specifically. This type of problem can be minimized by following rail industry standard specification and design review practices for advanced technology projects, and standardizing event recorder technology so that less customization is needed.

2.3.3 Handling the Data after Collection

Data is useful only if it can be presented in a form that can be easily interpreted. As the rail industry becomes more familiar with using data collection devices, the methods of sorting, selecting, and presenting the data are becoming more refined.

Early event recorders did not allow much flexibility in printing out their data. Some presented their contents without interpretation (such as in hexidecimal code). The current generation of presentation software allows data to be presented in easy-to-interpret column or graphic formats. A potential problem with newer event recorder data display software is that signal nomenclature may be misleading. It takes advance planning to assure that the signal nomenclature accurately explains the source of the signal.

Monitoring or logging devices delivered on new rail transit cars in the past decade have had human interface capabilities which could be useful in a number of different ways if presented or printed selectively, but early efforts at presentation had a variety of problems. A typical problem was that too much data was presented to personnel who did not need it or were not interested in it. Obtaining useful information by sorting through mostly irrelevant data was difficult. There have been instances where a monitoring system was ignored or even disconnected or removed because of data overload. Another problem was making the interface so complex that it was difficult to navigate to the specific information needed. Yet another was presentation of cryptic data codes. Agencies have learned to require customization of their user interfaces so the desired set of information is easily available to different employees needing it for their particular use or application purpose.

In the aviation industry, flight data recorders have enhanced the accuracy and completeness of accident and incident investigations. In addition, the Federal Aviation Administration (FAA) contends that implementation of enhanced data collection requirements by air carriers will provide sufficient data to recognize trends that may adversely affect flight operations. Manufacturers and operators can analyze these trends and take corrective measures to avoid potential accidents or incidents.

The FAA also believes that while improved inspection, maintenance, and training are important elements of preventing accidents, there is no acceptable substitute for the additional data that event recorders capture. The FRA and the NTSB have the same position for railroads and contend that rail transit can draw similar benefits from event recorders – using recorded data to detect technical flaws, unsafe practices, or conditions outside of desired operating procedures early enough to allow timely intervention to avert accidents or incidents. Enhanced rail safety will lead to lower costs over time as accidents and incidents are avoided.

As noted above, in the course of preparing this report, ATMS staff held a series of meetings with selected transit and industry experts. A summary of some of the information obtained is given in Appendix 2.

2.4 Historical Perspective on Accidents and Fatalities in the Transportation Industry

Since the widespread use of event recorders can be expected to contribute to enhanced safety in the rail industry, their potential benefit in reducing accidents and incidents needs to be explored.

It is difficult to quantify the cost or real risk versus the benefit to the public of *avoiding* potential accidents. Most available rail data pertain to freight railroad and passenger railroad operations, which are similar to but have important operational differences from commuter rail and rail transit operations. There is not yet much data available for commuter rail applications of event recorders, especially for the self-propelled EMU cars which are most similar to rail transit cars. Significant differences include the manner in which the passengers and the system interact, speeds and density of other rail traffic. The frequent starts and stops, door operations, and the continuous entry and exit of passengers differentiate commuter rail and rail transit from other types of rail operations, although the FRA has not yet addressed door interactions in the CFR.

It cannot be assumed that the level of damage or destruction in transit accidents is directly comparable to the majority of railroad accidents, and comparisons to air accidents are highly problematic. Thus, caution is needed in attempting to draw comparisons and conclusions from non-transit data.

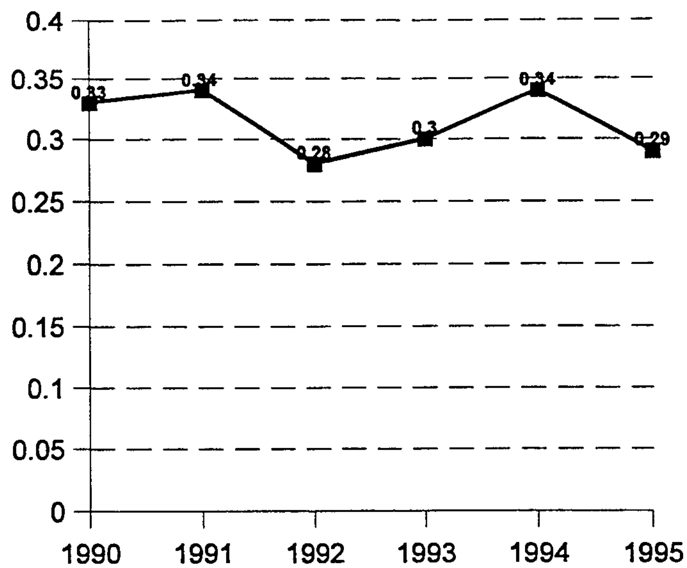
Railroad safety has generally improved over the past 20 years. Railroad accident rates are down from 1976 levels, but the rate of decline has slowed since 1987. The NTSB lists all rail accidents (railroad and transit) *together*, covering almost 30 years (1967 through early 1996). The accidents of interest for the purposes of this report represent 35 out of 209 accidents listed by the NTSB. The excerpted NTSB listing is reproduced in Appendix 3. *The modes of interest are Commuter Rail, Heavy Rail and Light Rail, using the APTA definitions.* (In general, the modes listed as Commuter Rail using APTA definitions are considered Railroads by the Federal Railroad Administration (FRA) and fall under FRA regulations concerning Event Recorders. Modes listed as Heavy Rail and Light Rail using APTA definitions generally do not fall under FRA jurisdiction and are not subject to the FRA event recorder legislation). Appendix 3a examines a sample of the more pertinent accidents in further detail.

The NTSB reports attempt to determine the causes and contributing causes of each accident. It is often difficult to determine the degree to which human error, training, mechanical design faults, or maintenance problems contribute to a specific accident. *A shared characteristic of the rail accidents chronicled by the NTSB is that an event recorder or monitoring device is helpful when present and would have been important if one had been available.* In some cases, the NTSB has recommended that the responsible organization install such devices, even if the agency is not regulated by the FRA.

Railroad accidents, with a death rate (reported by the National Safety Council for 1996) of 0.2 per 100,000 population, compare to air transport at 0.3 per 100,000, and to 0.1 per 100,000 population for "other" transport (injuries involving pedalcycles, animal-drawn vehicles, street cars, etc., except in collision with motor vehicles). The National Safety Council 1996 *Accident Facts* show railroad accident deaths to be a small fraction (2.36%) of all "public" non-motor vehicle deaths. Transit accidental deaths are again a fraction of the railroad total, although they tend to be covered in great depth by the media in the cities where they occur.

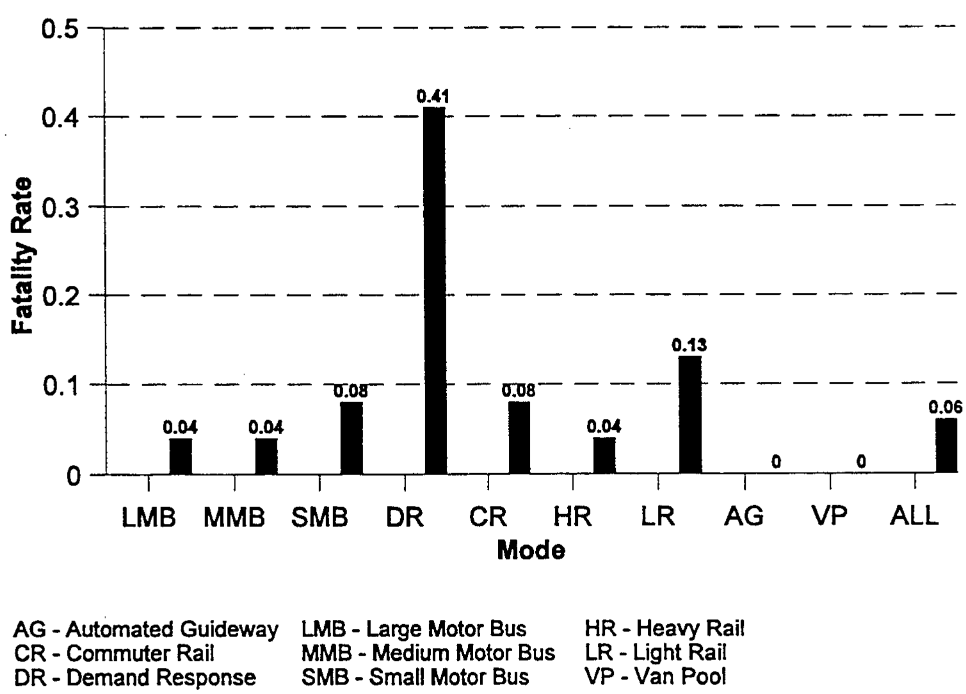
Looking broadly at accident and fatalities, the Federal Transit Administration's Safety Management and Statistics (SAMIS) 1995 Annual Report is instructive (FTA-MA-26-9033-97-1). Figure 2.1 shows transit system fatalities from all causes (except suicides) i.e., collisions, derailments, personal casualties and fires at 0.29 to 0.34 per 10,000,000 passengers carried, with total fatalities by year over five years ranging from 273 to 339.

Figure 2.1 - Fatalities from All Causes (per 10,000,000 Passengers)



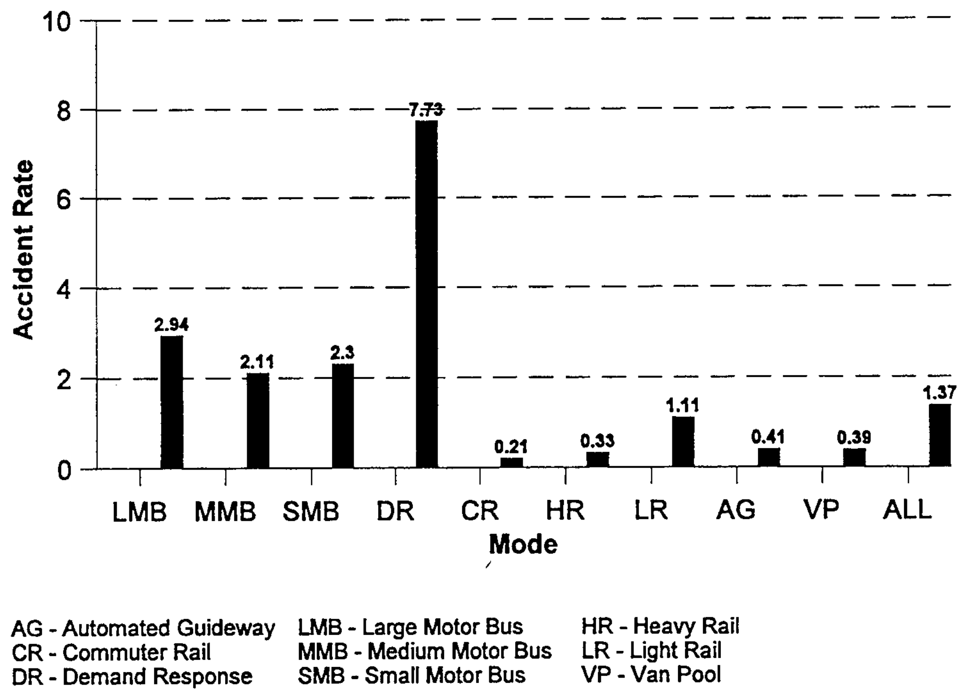
Looking further into fatalities by transit mode and year, Figure 2.2 shows that rail systems, with a fatality rate of 0.04 for heavy rail per 10,000,0000 passenger miles from collisions, derailments and personal casualties, compares favorably with several other modes.

Figure 2.2 - Fatalities by Mode (per 10,000,000 Passenger Miles)



Similarly, as shown in Figure 2.3, accidents per 1,000,000 passenger miles rates of 0.33 for heavy rail and 0.21 for commuter rail are lower than all other transit modes.

Figure 2.3 - Accidents by Mode (per 1,000,000 Passenger Miles)



For another comparison, there were 43,000 deaths and 2,600,000 disabling injuries from motor vehicle accidents in 1996, a death rate of 16.3 per 100,000 population.

2.4.1 Aviation Industry Parallels

With the enactment of the Air Commerce Act of 1926, the Federal Aviation Administration (under a previous name), began to regulate air commerce and has since assumed a primary role in regulating aviation safety. Minimum engineering standards were first set forth in October 1927. From the beginning, the government has employed numerous means to gain support and input from industry experts, and has achieved wide coordination of its plans, proposals, and regulations.

In assessing risks, costs and benefits of regulatory actions, aviation has applied what is widely recognized as the *mature operational judgment* of government and industry experts in setting aviation safety standards and policy. Such consensus building has proven to be far easier than development of believable cost/benefit analyses that clearly indicated that an investment was required. The enormous cost of a major accident and the risk of major fatalities justifies serious effort even if an expenditure cannot be justified on a pure economic basis.

One approach has involved establishment of a *"target level of safety,"* based on rational, numerical analyses. The approach was first invoked by the British Air Registration Board (ARB), the U.K. certifying authority, in the late 1950's. The Board called for a design that would have a failure rate of no more than one in ten million landings, ten times better than the rate then experienced in normal operations. The British Board was aware that the kind of analysis it was imposing would be valuable in evaluating *alternative courses of action* as to their *comparative* safety value.

Many people and organizations have since tested the idea, especially the *target* number of one accident in ten million events. A study done by the U.N. International Civil Aviation Organization RGCSP (Review of the General Concept of Separation Panel) in 1975, using UK mortality rates, showed that the *general* risk of mortality in the healthiest age groups was six in ten million person hours.

In a comprehensive study by several countries, the U.N. international aviation standard-setting body looked at fatality rates in manufacturing, railway work, public road vehicles; mortality rates in the general populations; and a variety of air accidents from landing to midair collisions. Their finding was that *an appropriate target level of safety might be between one and six fatal accidents in 10 million aircraft flying hours, with the resulting risk appropriately shared among mechanical failures, midair collisions, and other accident causes.*

III EVENT RECORDER TECHNICAL REQUIREMENTS FOR RAIL TRANSIT

Based on a review of the data recording requirements developed and tested by commuter railroads, the requirements of the Federal Railroad Administration (FRA), and the proposed IEEE standard, a minimum set of data points for rapid rail transit event recorders is presented in a summary form, including a set of construction/hardening requirements. This preliminary requirements set is applicable to all rapid rail systems, and is for the purpose of supporting incident/accident investigation. However, the more modern and automated systems will have additional data points readily available for recording uses other than incident/accident investigation, as discussed in earlier sections. Table 3.1 shows a comparison of data points currently gathered (or proposed in technical specifications) by several rail systems, those required by the FRA, and those proposed by IEEE.

Table 3.1 - Comparison of Data Collection and Recording Requirements

Item	FRA	PATH	M-N	LIRR	IEEE	WMATA	NYCT
Time	X		X	X	X	X	X
Master Controller (Throttle)	X	X	X	X	X	X	X
Master Controller (Braking)		X	X	X	X		X
Other Braking Commands	X	X	X	X	X	X	X
Brake Pipe Pressure		X	X	X	X	X	X
Brake Cylinder Pressure		X	X	X	X	X	X
Dynamic Braking	X	X			X	X	X
Propulsion (Motor)/Coast		X	X	X	X		X
Speed	X	X	X	X	X	X	X
Location (Distance)	X		X	X	X	X	X
Active Cab		X	X	X	X		X
Reverser (Direction)	X	X	X	X	X	X	X
Cab Signal	X		X	X	X	X	X
Door Status		X			X		X
Bypasses/Cutouts			X		X		X
Misc. Other Signals		X	X	X		X	X

Notes: Metro-North, Long Island RR and PATH are considered commuter railroads and fall under FRA regulation. NYCT and WMATA are considered rail transit. Metro-North and Long Island Railroad signals are from recent EMU event recorder retrofit installations. PATH signals are from an APTA paper on event recorder tests. IEEE signals are from Draft 3.0 of Draft Standard 1482.1. NYCT signals are from the R142 specification. WMATA signals are from recent technical specifications.

Among those listed, the IEEE, NYCT and WMATA specified survivability requirements.

3.1 Basic Data Collection and Storage Requirements for Rail Transit

Discussions in the IEEE Working Group 3 (WG3) regarding event recorder capability began with an in-depth mapping of what the FRA Event Recorder signal requirements would be if interpreted from the 49 Code of Federal Regulations (CFR), Section 229.5(g) (targeted initially for locomotives) to transit terms (self-propelled, permanently or semi-permanently coupled cars). Following is a list of the minimum set of data points that need to be captured by rail transit event recorders if they are intended to be considered compliant with the FRA requirements:

Table 3.2 - FRA Requirement for Interpretation for Transit Basic Event Recorders

Input #	FRA Requirement	Rail Transit Input Description
1	Train Speed	Speedometer, GPS or other signal
1a		Speed Sensor signal
2	Direction of Motion	Reverser Position
2a		Direction of actual movement
3	Time	Time including date, correctable to a time standard
3a		Time used by the train or agency
4	Distance	Odometer
5	Throttle Position	Master Controller Propulsion Commands, including Coast
6a	Brake Applications and Operations (include train brake, independent brake)	Master Controller Braking Commands, including Deadman & Emergency
6b		All other emergency commands initiated in the cab
6c		Brake pipe pressure
6d		Brake cylinder pressure (lead truck)
7a	If so equipped, Dynamic Brake Applications and Operations	Dynamic brakes enabled
7b		Traction Motor current/torque signal
8	Cab Signal Aspects	Cab Signal Aspects

There must be sufficient storage capacity for 48 hours of collected data.

The FRA requirements do not cover several key aspects of commuter rail and rail transit operations. Among those are door conditions, the most important of which assure that the doors are closed and locked when the train is in motion. The following additional signals, as summarized in Table 3.3, are needed to complete a basic set of signals considered necessary by rail industry experts:

Table 3.3 - FRA Requirements Extrapolated for Rail Transit

Input #	Added Requirements Needed for Rail Transit
1	Cab Active (Make Up Relay)
2	Emergency Brake Activation Mushroom Switch Signal
3	ATC Penalty Brake Activation Signal
4	Track Brake Activation Signal
5	Deadman or Alertor Penalty Brake Activation Signal
6	Doors Closed and Locked Summary Trainline
7	Door Open Command (Trainline/Local)
8	Zero Speed Detection

3.2 Enhanced Event Recorders

Beyond this list for the basic requirement, there are additional signals which are desirable for recording status of interfaces with passengers. Also on the Enhanced list, as summarized in Table 3.4, are signals relating to other technologies on vehicles which would provide information of interest.

Table 3.4 - Functionality Needed for Enhanced Event Recorders

Input #	Enhanced Input Description
1	Wheel Spin/Slide Activation
2	Handbrake Status
3	Snow Brake Status
4	Truck Cutout Status
5	Trip Cock Brake Activation Signal
6	Brake Assurance Decelerometer
7	Door Close Command (Trainline/Local)
8	End Door Open
9	Crew Door Open
10	Door Bypass
11	Door Cutouts
12	Door Over-ride (Prevent doors from opening)
13	Horn Activated
14	Bell Activated
15	Headlights On

Input #	Enhanced Input Description
16	Crossing Lights/Strobes/Marker Lights On
17	End Of Train Device Active
18	Uncouple Switch Activated
19	Cab Signal/ATC/ATS Cutout
20	ACSES Status
21	Car Number
22	CBTC Signals

Note: Certain of the signals must reflect consist status, not just the status of the car on which the event recorder is installed.

3.3 Monitoring and Diagnostic System Recorders

For Monitoring and Diagnostics, a wide variety of data may be of interest for different purposes. Normal status data may be listed and system fault data parameters defined for which events can be flagged when operating outside the normal operating window. The associated thresholds for these parameters will vary by the type of rail car and associated operating limits, accepted practices for safe operations, the duration of any irregularity, and other factors.

Table 3.5 is one approach to the types of data included in Monitoring and Diagnostic recorders:

Table 3.5 - Typical Capabilities Provided by Monitoring & Diagnostic Recorders

Power	Propulsion	Control Systems	HVAC
• DC Master Relay Coil • AC master Relay Coil • Pantograph Up/Down • Pantograph/3rd Rail voltage • 3rd Rail/Catenary On/Off Auxiliary LVS • 230 VAC/110 VAC Alternators/Motor Generators • Battery Charger • Battery	• Throttle Position • Direction • Speed • Wheel Slip Slide • Coast (BTR Coil) • No Motion (Traction Motor Interlock) • Traction Motor Blower • Inverter Discharge • Radiator Fan & Motor • Locked Wheel	*ATC Code Rate Track Signal Analysis* • Monitors Rail Signal & Independent Comparison to Onboard ATC • Locates Weak Rail Signals • 100 Hz Level Aspects • 250 Hz Level Aspects	• Coolant Compressor • Blower Fans • Interior/Ambient Temp • Heating Element • Thermostat • Trainline status Communications • Radio • Radio Battery Charger • Intercom/PA
Braking System	Motors and Gears	Doors	Annunciators/Misc.
• Dynamic & Blower • Eq. Reservoir • Pipe Pressure • Cylinder Pressure • Snow • Parking • Emergency • Contactors (BXR Coil)	• Temperature • Oil Pressure • Filter Blower	• Indicators • Commands • Cab/Non Cab Side Open/Closed • Cab/Non Cab Side Crew Key Switch • Door Relays	• Emergency Mushroom Switch • Emergency Trainline • Horn/Bell • Deadman • End of Train • Overspeed • Sanding Lever Switch

Other signals of interest may include circuit breakers, cutouts, interlocks, bypasses, key contactors and fault information needed by operating and / or maintenance personnel.

3.4 Survivability/Construction Requirements

It is critical that the event recorder not lose data in the event of an accident. It (or at least its memory module) must be constructed to survive certain environmental conditions as follows:

- Fire - 1200 degrees F for 30 minutes, followed by 570 degrees F for 60 minutes, followed by 212 degrees F for five hours.

- Impact Shock - 100 Gs peak, 65 ms duration, separately in the direction of each of the three principal axes.

- Penetration - 50 pounds weight with a protruding 0.25 diameter steel pin dropped from a height of 5 feet

- Static Crush - 25,000 pounds for 5 minutes

- Fluid Immersion - Immersion in any of the following individually for 48 hours: grade 1 and 2 diesel fuel, regular and salt water, and lubricating oil. Immersion in fire extinguishing fluids for 10 minutes followed by 48 hours in a dry location without otherwise being disturbed.

- Hydrostatic Pressure - Immersion in salt water at a depth of 50 feet for 2 days.

The requirements for each of these categories originated in the New York City Transit Authority's R142 specifications, and have since been adopted by other transit agencies and commuter railroads.

IV ASSESSMENT OF POTENTIAL COSTS AND BENEFITS OF EVENT RECORDERS

Excluding any government regulations, decisions concerning new equipment or subsystems, such as the installation of event recorders, involve the analysis of both benefits and costs, some with quantifiable monetary values and some without. Ideally, decisions to proceed with implementation will be made only in those cases where quantifiable benefits outweigh projected costs, unless other considerations such as public safety are predominant. For decisions with public safety implications, it is often difficult to make a simple monetary analysis.

4.1 Relevant Costs

As with most acquisitions involving new technologies, costs can be organized into various project life cycle stages, such as Planning, Design, Equipment Purchase, Installation, Operations and Maintenance. Each one of these is briefly discussed in the following paragraphs.

4.1.1 Planning and Design Costs

In the case of recorders, the first step is to decide which fleet segments are to have the new technology and how the installation will be implemented. If the recorders are to be part of a new car procurement or part of a planned overhaul, this will reduce installation costs.

Several issues need to be addressed:

- Which cars will be retrofitted, and in what priority order will this be accomplished?
- Will the recorders be used primarily for capturing accident data, or will additional features be included?
- Will a single integrated recorder be used, or will two systems - one for maintenance & diagnostics and one for accident & incident (event) recording be required?
- Is it practical to have uniformity among all car classes and cars in the fleet?
- How will the desired signals be obtained for recording by the event recorder?

The answers may be different for each type of car and, even different among cars within each fleet, depending on the extent of modifications that may have been made over the years. For instance, spare trainlines may have been used for various purposes. Modifications may have been prototyped on some cars in the fleet and not entirely removed. Repairs may have been accomplished, but the changes not fully documented. Some cars may be old enough to lack accurate schematics.

Once basic decisions have been made, technical specifications must be written. A number of specifications have been used by railroads (and now rail transit agencies), but they may not be directly applicable, since the equipment and the operational environments are likely to be significantly different from agency to agency and car class to car class.

The procurement process follows specification development, resulting in bids for the hardware and related logistics support. Part of the effort will be to specify an appropriate maintenance concept since it will be a significant cost driver.

4.1.2 Equipment Costs

Virtually all recorders now being built are capable of providing more information than the minimum requirements for accident and incident investigation. It is likely that many, if not most, buyers will opt for more than the specified minimum capability. It is also probable that manufacturers will provide the minimum basic capability simply by disabling (or perhaps not providing) the internal circuit cards that provide the additional functions.

The basic equipment costs associated with implementing recorders depend upon various factors, such as the technology used to capture data and the number and types of diagnostic signals to be recorded. Sensor and wiring requirements will influence equipment costs.

4.1.3 Installation Costs

A key cost issue involves the installation of the recorders, data lines, and sensors for retrofit installations, especially when installation in older cars is being considered. Most locomotives and MU cars currently being manufactured have made provisions for (or already have) recorders and the most commonly specified sensors and data lines. Most rail transit vehicles are being designed with some level of car monitoring and diagnostic capability, and it typically includes most of the signals needed for basic event recorders. In these cases, a requirement to have an event recorder installed on newly purchased cars will be most cost-effective, especially if the cost burden can be partially offset against maintenance and diagnostic benefits. Another factor concerns the availability of data bus systems. If a data bus is available, installations costs should be significantly lower than if fully hard-wired systems are contemplated.

The IEEE Rail Transit Interface Standards Committee Working Groups have developed a classification of the complexity of vehicle interfaces which is applicable. Three types of interfaces (Type I, Type II, and Type III) are defined in Draft Standard IEEE P1475/D4.0. They apply to the *kinds* of installations that are considered practical:

> **Class 1**: An event recorder installation in older transit cars, in which the design and construction of the cars includes no provisions for the physical installation of the equipment, remote sensors, or displays, and where the installation of cables may be difficult. This kind of installation generally utilizes Type I, unsophisticated interfaces.
>
> **Class 2**: An event recorder installation in more recently built transit cars, in which the design and construction anticipated future equipment, remote sensor, display and cabling requirements, and elementary provisions for retrofit exist. This kind of installation generally utilizes Type II, mixed interfaces. Overhauls of existing fleets may fit this category if advanced technologies are being utilized in the overhauled systems.
>
> **Class 3**: An event recorder installation in transit cars during design and construction, when the equipment, remote sensor, display and cabling requirements can be easily incorporated in the design. This kind of installation generally utilizes Type III, flexible and complex interfaces.

There will be many variations within these three classes of installation, and thus important differences in the costs and complexities of installation. However, these three classes can be used to indicate the cost *ranges* to be expected.

Integrating recorder systems into existing rail equipment already crowded with existing wiring – or where spare wires are limited or already assigned – may be difficult and costly. A large burden of labor and technical difficulty is associated with installing new cables. A further concern is signal attenuation caused by long cable runs and possible contamination by electrical noise.

Lack of adequate documentation of earlier modifications can be a serious problem. The source documents for older rail cars (i.e., 30+ years old) may not be dependable. Older cars may contain system modifications that are not fully reflected in current system drawings. For example, during the installation of event recorders on a recent Commuter Rail project, one installation obstacle was that wires and signal pickup points had in numerous cases been "customized" by maintenance crews over the lifetime of the rail car. Even within identical rail car types, it was discovered that wiring configurations were often different. Inadequate documentation complicates the installation process and increases program *cost* and *risk*.

4.1.4 Operating and Maintenance Costs

When a transit agency initially installs event recorders, it must decide if a transit train will be allowed to remain in service without fully functional event recorders. If the answer is yes, the recorders will need to be added to the minimum required equipment list, and there will be consequences. It is self-evident that very high recorder reliability and availability are important attributes. If the recorder equipment is not highly reliable, failures could serve to keep cars out of service.

It is important that the sensors, wiring or piping installed specifically to support event recorder data collection not be the source of failures not experienced otherwise. For example, if the air system is tapped for a brake pressure reading, the sensor or tap must not be allowed to reduce the reliability of the air system.

If the event recorder is considered essential equipment, there will need to be a means of easily determining whether the unit is operating properly. Most event recorders have been designed with an indicator that shows "go" or "no go" after a power-up self-test sequence. That indicator can be mounted near the operator location or near other equipment that must be checked (by operating or maintenance staff) prior to putting the cars into service. The inspection function will need to be integrated into existing routines. It is unlikely that an operating agency would add a new job function to inspect event recorders prior to service. The checking of a "go/no go"indicator by an employee who already has to check other things would normally not lead to a significant added workload.

Most operating agencies have inspection and maintenance cycles for all equipment. The recorder adds some labor. Typically, recorders must be inspected every 60-90 days, using a more extensive test procedure than the internal power-up self-test. The latter would normally be done without removing the equipment from the car.

If testing can be coordinated with other car testing so that all inputs are exercised (power, braking, door operation, etc.) and the data only need to be downloaded or accessed by a laptop PC, the time required will be small. It will be perhaps an hour or less for one person, with another person checking a printed version of the test record. This assumes that it is easy to see that the performance is as expected. If each car system providing input signals for the event recorder must be exercised separately to validate the operational status of the event recorder, it could take a two person crew a whole shift to perform a validation. Recorder manufacturers recognize this maintenance problem and are beginning to supply portable test equipment that can exercise all of the input channels without the need to involve each and every car system separately. If repairs are necessary, most recorders can be removed from the car relatively quickly (within 30 minutes).

There is debate in the rail industry whether operating authorities should perform their own maintenance on event recorders. The rail transit industry typically requires that all equipment (including safety critical systems) be maintainable in-house, down to the component level. Event recorders use the same technology as many advanced technology (microprocessor-based) systems. If a transit agency already has a staff capable of maintaining such systems, additional training costs will be minimal.

Some manufacturers advocate that the recorders be provided as sealed units, with only factory repair authorized, in order to minimize tampering. This would offer the potential for manufacturers to provide reliability warranties, agreeing to provide all repairs at a firm fixed price over a three to five year period.

4.2 Cost Estimation Approach Framework

Table 4.1 provides cost elements, broken out as discussed above. The costs will not be the same for different desired recording capabilities and will also vary depending on the class of installation required. Thus, the rough order of magnitude cost estimates provided have been based on different *types* of recorders, as well as the different *classes* of installation that were defined earlier. Also, the estimates provided should primarily be used for comparison purposes in that there will be important differences even within the types and classes defined.

4.2.1 Recorder Types

1. Basic Event Recorders
2. Enhanced Event Recorders
3. Monitoring & Diagnostic Recorders

4.2.2 Installation Classes

Class 1 - Recorder installation in older transit cars
Class 2 - Recorder installation in more recently built transit cars
Class 3 - Recorder installation in transit cars during design and construction

Table 4.1 - Event Recorder Cost Elements

COST ELEMENTS/ACTIVITIES	NOTES
Engineering and Design Costs	• Specification Development
Equipment Costs • Event recorder • Sensors • Wiring costs • Ancillary systems • Vendor support	 • Cost to purchase • Costs associated with the acquisition of any non-existing, but required sensors. • Costs associated with any wiring from recorder to sensor, plus power wiring. • Systems for downloading data or maintenance • Costs for manuals, maintenance, help line, etc • Test Equipment
Installation Costs (Owner)	• Retrofit vs. New Installation • Car Modifications • Dismantling • Testing
Operating & Maintenance (O&M) Costs	• Maintenance/Data Collection Costs • Replacement • Recurring Training • Logistics (System Spares)

4.3 Major Costs Elements

Table 4.2 summarizes equipment and installation costs for both new and retrofit systems for four commuter railroad operations involving EMU installations. These data are of interest because the installations have much in common with rail transit cars of the same vintage, and thus the experiences would be directly applicable. It should be noted that the retrofit costs for both NJ Transit and SEPTA consisted of "upgrading" the existing Cab Signal System and not starting from initial installation with respect to cables, sensors, etc.

Table 4.2 - Basic Cost Information

Railroad/ Operating Authority	Supplier/ System	Material Price	New/ Retrofit	Installation Labor	Ancillary Systems	Maintenance
NJ Transit	Quantum/ Event Recorder	$ 3,650. (51 chan.)	New	$ 1,620		N/A
		$ 2,937 (51 chan.)	Retrofit[1]	$ 1,260		N/A
SEPTA	Harmon/ Event Recorder	$ 6,500 (42 chan.)	Retrofit[2]	$ 2,000		N/A
Long Island Rail Road	Peerless 1230/ Event Recorder	$ 7,000 (34 chan.)	Retrofit			
Metro-North Railroad	Peerless 1250/ Health Monitoring System	$ 28,000[3] (305 chan.)	Retrofit	$ 13,000	$ 5,000	1-2 hours, On a 60 Day Cycle

1. The new recorders are totally interchangeable with the upgraded recorders (bolt for bolt, pin for pin and capable of being installed in the same location). The new and upgraded recorders include the appropriate interface, all sensors, wiring harnesses, download cables, air pressure switches, pressure manifolds, transducers, and are furnished as a complete kit for installation.

2. Recorder was modified to fit the currently installed Cab Signal System.

3. Price per Kit. Kit includes complete wiring harness designed to be compliant with a particular M-Series rail car and system training and operating manuals.

4.3.1 Recorder and Ancillary Equipment Costs

As discussed in Appendix 4 and its tables, manufacturers were contacted to gather information.

A 30-35 channel (enhanced) event recorder is estimated at $6000-8000 per unit. The average cost for a minimum requirement (basic) event recorder is approximately $5,000.

Typical ancillary systems cost is approximately $5,000. The number of ancillary systems depends on the railroad's system configuration. For example, Metro-North Railroad utilizes 14 data acquisition sites with personnel computers and printers.

A fully capable monitoring and diagnostic recorder for retrofit has been estimated to cost about $25,000 on average.

NJ Transit developed a detailed technical specification for the purpose of purchasing new event recorders and upgrading existing microprocessor event recorders that were part of the US&S cab signal system. The new recorders were to be totally interchangeable with the upgraded recorders (bolt for bolt, pin for pin and capable of being installed in the same location). The new and upgraded recorders were to include the appropriate interface, all sensors, wiring harnesses, download cables, air pressure switches, pressure manifolds, transducers, and were to be furnished as a complete kit for installation.

The following NJ Transit commuter rail costs are broken down into two separate categories: **New** – which consists of the cost of the new recorder, associated material, labor and project administration, and **Upgraded** – which consists of the cost associated with the retrofit of the existing microprocessor recorder, associated material, labor and its project administration.

4.3.2 New Recorder and Installation

Material	$ 3,650.00
Labor	$ 1,620.00
Project Administration	$ 265.00
Total Per Unit Installation	**$ 5,535.00**

4.3.3 Upgraded Recorder and Installation

Material	$ 2,937.11
Labor	$ 1,260.00
Project Administration	$ 210.00
Total Per Unit Installation	**$ 4,407.11**

4.3.4 Installation Costs

As noted above, installation costs vary widely depending on whether the cars are old or new and whether the number of channels is minimum or extensive.

4.4 Conclusions - Potential Benefits of Event Recorders

Benefits from the use of event recorders, either separately or in combination with the monitoring and diagnostic capabilities, can be realized in three primary areas: *enhanced safety, higher equipment availability, and lower O&M costs.* The safety benefits from the implementation of rail event recorders accrue in two interrelated areas. There are inherent, non-measurable benefits that evolve from the availability of useful and detailed accident and incident data from which the rail industry can draw as a resource. Further, there are the direct, measurable benefits that would result from potentially *averting* an accident by detecting negative trend information, related to equipment and/or operator functioning.

Trend analysis provides valuable information, especially in terms of whether performance is improving, holding steady, or deteriorating. Aggregate trends over time can provide rail transit managers with a valuable perspective on potential problems that would otherwise not be visible. On the basis of the trend analysis, managers can reduce or eliminate out-of-tolerance conditions by focusing on the causes, and then implementing appropriate corrective action.

Comprehensive data can be used as an investigative tool when accidents and incidents do occur, and trends that may adversely affect rail operations can be determined. Based on experience from the aviation industry, it can be concluded with virtual certainty that widespread use of event recorders and analysis of their data in the rail industry will lead to a reduction of accidents and saving of lives. Railroad experience to date supports this prediction. Although the NTSB accident investigators are skilled at determining the probable cause(s) of accidents, the value of event recorder data is in providing additional facts precisely. Railroads and transit agencies desire enough data to positively determine the cause(s) of an accident so that another from the same cause may be prevented. Agencies are eager to improve maintenance and operating procedures, training, rule enforcement and all facets of equipment procurements in any way which improves safety and effectiveness. Event recorder data is a powerful tool to that end.

The benefits achieved from the installation of event recorders begin to accrue immediately. Recorders can improve car safety and operations and maintenance by providing information that rail operators and maintenance personnel have lacked – documented data on precisely when and where a failure or deterioration has occurred. Analysis of data obtained from recorders can quickly and accurately identify equipment problems, significantly decrease costly and often erroneous failure diagnoses, enable faster equipment processing through the maintenance facility, and result in increased equipment availability.

Rail transit and freight railroads spend a significant portion of their operating budgets on problem diagnosis and maintenance of equipment systems and subsystems. The diagnostic tasks associated with maintenance activities have a substantial influence on overall maintenance costs as well as car and locomotive safety, reliability, and availability. Although it is difficult to quantify the diagnostic portion of the total maintenance cost to railroads and transit agencies, it is significant. Several industry experts predict that the combined use of event recorders with monitoring and diagnostic equipment will reduce diagnosis time by at least 50 percent. Mis-diagnoses of equipment faults may result in inappropriate repairs or "no defect found" conditions, and could potentially lead to accidents.

Advanced monitoring and diagnostics systems – coupled with the latest in event recorder and radio technology – can provide key failure data to rail car maintenance and engineering personnel. In addition, these systems also provide information pertaining to safe operating practices and rail car conditions. Event recorders provide the dual benefit of increased revenue through reduced repair costs and improved safety. In addition, rail event recorders facilitate accident investigation and reconstruction. They serve to accelerate re-creation of accidents down to the smallest detail and thereby, aid in the discovery of underlying or potential accident causes.

4.4.1 Safety

The obligation to increase safety for rail passengers, employees, property, and the general public includes preventing incidents and accidents; reducing deaths and injuries to passengers and operations personnel; preventing damage to cars; and reducing errors that may lead to accidents or incidents. Table 4.3 highlights areas of safety benefits.

Table 4.3 - Safety Benefits

ECONOMIC FACTORS	RELATED CAUSAL FACTORS
• Value of fatalities avoided • Value of property damage avoided • Value of injuries avoided • Value of damage/destruction avoided • Value of accident investigation costs avoided	• Reduced operator errors • Reduced equipment failures • Increase diagnosis of real-time problems

4.4.2 Operations and Maintenance Productivity

Table 4.4 highlights areas of operations and maintenance productivity benefits.

Table 4.4 - Operations and Maintenance Benefits

Revenue Service	Personnel/Resources	Inventory Control
• Immediate Failure Confirmation • Reduced Diagnostic Time • Accurate Fault Identification • Reduced Repair time • Improved MDBF	• Rapid Diagnosis Reduces Labor • Improved Shop Management • Improved Utilization of Shop Resources • Reduction in Unscheduled Maintenance • Automated Paperwork	• Improved Spares Management • Eliminates Unnecessary Repairs • Automated Documentation • Database for Inventory Planning
Result: Increased Equipment Availability	Result: Lower Labor & Shop Costs	Result: Lower Spares Costs & Effective Inventory Planning

4.4.3 System and Personnel Performance

The recorder can be used beneficially to record activities associated with the cars, overall system performance and management, as well as the performance of vehicle operators. The activities of operators such as sequence of actions, frequency, adequacy, effectiveness, and history can be evaluated to determine the proficiency of the vehicle operator. This can be used to determine if additional training is required, or if there is a deficiency associated with a particular operator that needs to be corrected. The recorder has a role in providing information that may prevent development of hazardous conditions.

An additional benefit of event recorders and monitoring & diagnostic systems is that such equipment requires a high level of systems integration on the cars. There are instances where the detailed design review for such systems resulted in a design scrutiny which improved the design or reduced the cost of systems being monitored.

4.5 Conclusions - Assessment of Potential Costs and Benefits

4.5.1 Summary of Major Costs

Table 4.5 depicts a set of cost estimates under six different scenarios. The cost elements used are those described in Section 4.1 above: *Engineering and Design Costs; Equipment Costs; Installation Costs; and Operating and Maintenance Costs.*

Table 4.5 - Estimated Recorder Life Cycle Costs

Cost Elements	Not Yet in Service		Recent Vintage Car (0-15 Years Service)		Older Car (16+ Years Service)	
	Enhanced Recorder	M&D Recorder	Enhanced Recorder	M&D Recorder	Enhanced Recorder	M&D Recorder
Engineering and Design	$100K	$150K	$150K	$200K	$175K	$225K
Equipment Costs/Unit[1]	$12K	$25K	$13K	$27K	$15K	$30K
Estimated # Installed Units Required	8750[2]	8750[2]	4325	4325	5832	5832
Equipment Costs (Fleet)	$105M	$219M	$56M	$117M	$87M	$175M
Investment Spares & Test Equipment (12.5%)	$13M	$27M	$7M	$15M	$11M	$22M
Installation Costs/Unit	$6K	$8K	$10K	$15K	$15K	$20K
Installation Costs (Fleet)	$52.5M	$70.0M	$43.0M	$65.0M	$87.0M	$117.0M
O & M Cost Factor	5%	5%	5%	5%	5%	5%
O & M Cost per Year/Unit	$5.3M	$11.0M	$2.8M	$5.9M	$4.4M	$8.8M
O & M Costs Over Life Cycle	$185.5M	$385.0M	$79.8M	$168.2M	$44.0M	$88.0M
Estimated Life Cycle	35 yrs	35 yrs	28.5 yrs	28.5 yrs	10 yrs	10 yrs

1. Includes wiring, ancillary systems, sensors, manuals, warranty costs
2. Assumes 500 new cars per year (5% of 10,000) over next 17.5 years (midpoint of 35 year life cycle)

Two recorder types were included: *Enhanced Event Recorders and Monitoring & Diagnostic Recorders.* The enhanced recorders provide the capability to record approximately 30-35 data channels, while the Monitoring & Diagnostic recorders provide a fully capable monitoring and diagnostic system. Because virtually all recorders now being built provide more than minimum capability, the basic event recorder option having only a 8-12 channel capability was not used as a cost alternative.

For equipment costs, the mid-point of an estimated range was used, based on vendor-estimated prices. Based on an estimated installation base (equipping all cars of that class in service throughout the U.S.) an estimated total equipment cost was computed for each installation class.

The estimated installation cost base was obtained from APTA statistics captured to reflect vehicle age for transit systems. Table 4.6 breaks out vehicle age for each heavy rail system into categories. Fifteen (15) years was used as the breakpoint. The potential new cars cost base was estimated at 5 percent per year of total fleet size based on an average age of heavy rail cars of 20.8 years. The 5 percent reflects both growth and replacement due to age. A 35 year life cycle was used. The estimated installed base for new cars is the 5 percent replacement factor times the mid-point of a 35 year life cycle. This allows a 35 year life cycle to be completed.

Table 4.6 - Age Distribution of Heavy Rail Vehicles

	AGE OF REVENUE SERVICE VEHICLES		
Name	**0 - 15**	**over 15**	**Total**
BART (San Francisco)	172	426	598
WMATA (Washington)	466	298	764
MDTA (Miami)	136	0	136
MARTA (Atlanta)	192	48	240
CTA (Chicago)	852	378	1230
LACMTA (Los Angeles)	84	0	84
MBTA (Boston)	264	144	408
MTA (Baltimore)	100	0	100
PATCO (Philadelphia)	46	75	121
MTA-NYCTA (New York City)	1792	4009	5801
PATH (New York/New Jersey)	95	247	342
RTA (Cleveland)	59	0	59
SEPTA (Philadelphia)	151	207	358
Heavy Rail Transit Cars	4,409	5,832	10,241

The estimates assume a maintenance concept under which the units are removed and replaced and returned to either a vendor or operating authority facility for repair. A 12.5 percent factor (of total equipment costs) was used for estimating the cost of spare units and test equipment. This factor was estimated by recorder manufacturers.

The costs of the three classes of installation were estimated based on the age of the cars to be equipped or retrofitted. Fifteen years was chosen as the break-point in the analysis. Cars with 15 years service or under were considered Class 2, while those with more than 15 years were put into Class 1. Installation costs and planning & design costs will be higher for older cars. It should be noted that where data buses are available in the car's control system, recorder installation costs are likely to be lower; however, no allowance for such savings was made in this analysis.

An Operations & Maintenance (O&M) factor of 5% per year for each type of recorder was established based on industry estimates. This factor estimates the percentage of equipment cost that will be required to operate and maintain the recorder system each year. Applying this factor provides the estimated O&M cost per unit per year. O&M costs assume that Go/No-Go inspections will be part of the normal inspection process for critical components as discussed above. A 90-day cycle for downloading recorder data was assumed.

The O&M unit costs were multiplied by the estimated installation base cost to compute estimated fleet O&M costs per year. These were then multiplied by the estimated remaining life cycle of the installation class to compute life cycle O&M costs. 35 years was used for new cars, 28.5 years for cars under 15 years old, and 10 years for cars older than 15 years. All costs are in Fiscal Year 1998 dollars.

This cost analysis provides only a rough order of magnitude of estimated costs. As more information and experience is gained, confidence in the estimates will increase, based on real world operational data.

4.5.2 Assessment of Benefits

The primary benefits associated with the use of event recorders, beyond the analysis of accidents and incidents, can be categorized into reduction of Operations and Maintenance costs and the potential *avoidance* of accidents and incidents. While these benefits will be greatest for enhanced recorders, even basic recorders are likely to be valuable.

4.5.2.1 Reduced O&M Cost

Universal adoption of monitoring and diagnostic systems can be expected to result in increased availability and reduced operations/maintenance costs by reducing the time required to troubleshoot and correctly identify the causes of failures. Even if only a basic event recorder and not a fully enhanced system, some benefits can be expected. Although industry experts contend that diagnostic time could be cut in half, sufficient data is not available to directly tie this to maintenance cost savings or to increased revenue service as a result of reduced downtime that would accrue due to increased success in troubleshooting failures. Efforts to gather additional cost data in support of this analysis are continuing. Further, more study is also needed to determine how much increased revenue service availability could be achieved through more accurate troubleshooting, and how much additional revenue could be achieved as a result.

4.5.2.2 Accident and Incident Avoidance

It is intuitive that universal application of event recorders separately or in combination with the monitoring and diagnostic system is likely to lead to a reduction of accidents. Yet, there are no reliable estimates that would quantify how much reduction in accident probability could be achieved. Current industry estimates place the replacement cost of a rapid rail car at approximately $2 million. Further, the U.S. Department of Transportation generally asserts that a human life equates to $2.7-3 million in its analyses of safety issues.

While a potential dollar benefit could conceivably be developed for avoiding a hypothetical accident, no attempt has been made to do so in this analysis due to the inability to estimate how much the probability of accident occurrence would be reduced through the use of event recorders.

APPENDIX 1

SELECTED DEFINITIONS

SELECTED DEFINITIONS

Basic Event Recorders: Used for *accident/incident analysis* by transit management and government investigators, primarily intended for after-the-fact collection of data needed for analysis of accidents/incidents.

Class 1 Installation: An event recorder installation in older transit cars, in which the design and construction of the cars includes no provisions for the physical installation of the equipment, remote sensors, or displays, and where the installation of cables may be difficult. This kind of installation generally utilizes Type I, unsophisticated interfaces (as described in draft IEEE Standard P1475/D4.0).

Class 2 Installation: An event recorder installation in more recently built transit cars, in which the design and construction anticipated future equipment, remote sensor, display and cabling requirements, and elementary provisions for retrofit exist. This kind of installation generally utilizes Type II, mixed interfaces (as described in draft IEEE Standard P1475/D4.0). Overhauls of existing fleets may fit this category if advanced technologies are being utilized in the overhauled systems.

Class 3 Installation: An event recorder installation in transit cars during design and construction, when the equipment, remote sensor, display and cabling requirements can be easily incorporated in the design. This kind of installation generally utilizes Type III, flexible and complex interfaces (as described in draft IEEE Standard P1475/D4.0).

Commuter Rail: Short to medium distance rail passenger service operating between metropolitan and suburban areas. Also known as "regional rail" or "suburban rail."

Commuter Rail Car: Commuter rail passenger vehicle. There are two types:

- **Commuter Rail Passenger Coach** - Not independently propelled and requiring one or more locomotives for propulsion.
- **Commuter Rail Self-Propelled Passenger Car** - Not requiring a separate locomotive for propulsion. "MU" or multiple unit cars may be electric ("EMU") or diesel powered.

Commuter Rail Locomotive: Commuter rail vehicle used to pull or push commuter rail passenger cars. Locomotives do not carry passengers.

Enhanced Event Recorders: Recorders that provide basic event recorder functions as well as the capability to record performance of various transit train/operator functions as to sequence, frequency, adequacy, effectiveness, and history. Used for downloading and use by maintenance personnel for *diagnosis* and/or for engineering and administrative management to establish *system performance*.

Event Recorder (draft IEEE Standard P1475/D4.0): An on-board device/system with crash-worthy memory which records data to support accident/incident analysis.

FRA Event Recorder (CFR 49 Section 229.5(g)): A device that monitors and records data on train speed, direction of motion, time, distance, throttle position, brake applications and operations (including train brake, independent brake, and, if so equipped dynamic brake applications and operations) and, where the locomotive is so equipped, cab signal aspect(s) over the most recent 48 hours of operation.

[See TRB definition of Rail Rapid below]

Heavy Rail: High-speed, passenger rail cars operating singly or in trains of two or more cars on fixed rails in separate rights-of-way from which all other vehicular and foot traffic are excluded. Also known as "rapid rail," "subway," "elevated (railway)," or "metropolitan railway (metro)."

Heavy Rail Car: Rail car with motive capability, driven by electric power taken from overhead lines or third rails, configured for passenger traffic and usually operated on exclusive right-of-way.

Light Rail: Lightweight passenger rail cars operating singly (or in short, usually two-car, trains) on fixed rails in right-of-way that may not be separated from other traffic for much of the way. Light rail vehicles are driven electrically with power being drawn from an overhead electric line via a trolley or a pantograph. Also known as a "streetcar," "tramway," or "trolley car."

Mass Transportation: Transportation by bus, rail, or other conveyance, either publically or privately owned, providing to the public general or special service (but not including school buses or charter or sightseeing service) on a regular and continuing basis. Also known as "mass transit," "public transportation." and "transit."

Metropolitan Railway (APTA): Another name for "Heavy Rail."

Monitoring & Diagnostic Recorders: Recorders that incorporate functions of basic and enhanced event recorders as well as the capability to *monitor* performance and help in *diagnosis* of problems in real time to serve the operator (with appropriate displays), and/or for gathering historical performance data. This type of recorder may also record a larger number of functions over a greater range of frequencies than basic or enhanced event recorders.

Rail Rapid (heavy rail transit, rapid rail transit): A transit system that generally serves one urban area, using high-speed, electrically powered passenger rail cars operating in trains in exclusive rights-of -way, without grade crossings (Chicago is an exception) and with high platforms. The tracks may be in underground tunnels, on elevated structures, in open cuts, at surface level, or any combination thereof. Some local terms used for rail rapid transit are *the elevated, the metro, the metropolitan railway, the rapid, the subway, the underground* - From *Urban Public transportation Glossary*, Benita Gray, Editor, Transportation Research Board, National Research Council, 1989.

Rapid Rail (APTA): Another name for "Heavy Rail."

Rapid Transit (APTA): Rail (or motorbus) transit services operating completely separate from all modes of transportation on an exclusive right-of-way.

APPENDIX 2

RELEVANT OBSERVATIONS BY TRANSIT AND INDUSTRY EXPERTS

RELEVANT OBSERVATIONS BY TRANSIT AND INDUSTRY EXPERTS

In the course of preparing this report, ATMS staff held a series of meetings with selected staff of the American Public Transit Association (APTA), the Federal Railroad Administration (FRA), and the Washington Metropolitan Area Transit Authority (WMATA) and conducted numerous discussions with rail transit and industry experts. The following provides some of the information obtained:

- State-of-the-art equipment manufacturers of transit equipment have embedded recording and data collection equipment, primarily aimed at the monitoring/diagnostic functions.

- FRA is in the process of developing the ruggedization requirements for accident survivability. There are currently no standards in the CFR.

- There is an on-going review of the current FRA regulations concerning event recorders. Items being reviewed or decided include parameters to be recorded and survivability requirements. Parameters on which decisions remain to be made include throttle position, speed, and brake application (who performed it - engineer/passenger/other crew?). There is no requirement to record voice.

- The requirements associated with accident/incident event recorders are likely to be somewhat different from those for the monitoring and diagnostic systems, but they are coming together and can be very complimentary.

- A minimum of 8 signal classes needs to be recorded and data need to be recorded at twice the frequency of the event.

- Most manufacturers make recorder boxes only, but not necessarily the associated sensors. For some functions it may be possible to plug into existing sensors.

- It may be difficult in some cases to justify event recorders purely from an economics viewpoint. They do not prevent accidents; they only provide information that may help prevent future accidents. Unlike aircraft accidents, evidence/causes are not normally destroyed in an accident.

- Ninety percent of all locomotives are equipped with event recorders. These event recorders are built-in and come with new locomotives, and therefore, there is no retrofit problem.

- Although current FRA regulations only require event recorders in the lead locomotive of a train consist, most locomotives have them because a consist can change.

- Experts felt that, as electronics has advanced from transistor/discrete integrated circuit logic to microprocessor based logic, reliability of nearly all electronic equipment, including event recorders has increased greatly. The amount of data which can be conveniently collected has increased greatly at a significantly lower cost.

- Maintenance and diagnostic monitoring equipment improves reliability by warning of impending failures (trend analysis) or aiding in locating existing faults. This tends to improve the efficiency of maintenance activities significantly, and reduces or maintains the same number of maintenance personnel required as the transit system grows. All of this reduces O&M costs.

- Maintenance personnel like the system; operators may or may not. The data collected by the present event recorders is used mostly for maintenance purposes.

- The scan rate for data is approximately 100 ms and this is probably too fast for normal events. It causes storage space to be used quickly which reduces the time frame of data stored before over writing. A rate of 250ms is probably sufficient. However, these rates do not catch anomalous events that happen in micro- or nano- seconds, such as voltage or logic spikes.

- WMATA is evaluating proposals for a new event recorder system. This new system will monitor approximately 176 data points, mostly for maintenance. (However, the specification states *"This data shall include all Federal Railroad Administration (FRA) mandated vehicle signals."* RFP Section 12.6.1, Point 1.) Hardening and location on the vehicle of recorders is important to WMATA. WMATA plans to have one recorder per married pair of cars. A married pair is two cars which cannot operate independently. The minimal consist is two cars. The system operates with a minimum of one married pair up to a maximum of four married pairs.

- All cars that are currently in operation in the WMATA system are wired for event recorders or maintenance monitoring devices and can handle the new specification. All new cars, under the new specifications, will be equipped with the new maintenance and diagnostic devices when delivered. Therefore, retrofitting is not a problem for WMATA..

APPENDIX 3

EXCERPTS OF RAIL ACCIDENTS LISTED ON THE NTSB HOME PAGE

EXCERPTS OF RAIL ACCIDENTS LISTED ON THE NTSB HOME PAGE

The National Transportation Safety Board (NTSB) is an independent Federal agency. Established in 1967, the agency is mandated by Congress (through the Independent Safety Board Act of 1974) to investigate transportation accidents. Its reports are available to the public. The agency maintains a web site listing the available publications. The NTSB Home Page of publications on Railroad accidents lists 209 reports, in rough chronological order. The list of Railroad accidents includes all rail modes, whether or not they occur under FRA jurisdiction. For a future study, it would be interesting to determine how many of the 209 accidents involved trains with event recorders (required equipment for less than a decade), and to evaluate the degree to which the event recorder data contributed to determining the probable causes and potential future prevention of the accident.

For this report, 35 of the 209 listings were excerpted (listed below). They may be of interest, based on the limited information available in the excerpt, either because they were commuter rail accidents, potentially involving EMU (electric multiple unit) cars, or because they were rail transit accidents.

Of the following list, some of the cars may have had event recorders. An "APTA classification" entry was added to each listing to indicate the most likely rail mode (the NTSB does not classify the rail modes).

An "Event Recorder?" entry was added to each one to indicate how likely the cars were to have an event recorder on board. ("No" is used where the transit agency was known not to have event recorders installed; "Yes" is used only when the car(s) involved in the accident is (are) known to have had an event recorder; "Probably" is used where the railroad is known to have been equipped with event recorders at the time of the accident; "Probably not" is used when the accident happened before the CFR which requires event recorders on FRA regulated rail modes became effective.)

NTSB Report Number - RAR-97-01, *Adopted on* 03/25/1997
Order NTIS Report Number - PB97-916301
Title: Railroad Accident Report Near Head-on Collision and Derailment of Two New Jersey Transit Commuter Trains Near Seacaucus, New Jersey February 9, 1996
APTA classification: Commuter Rail
Event Recorder? Probably

NTSB Report Number - RAR-96-04, *Adopted on* 10/29/1996
Order NTIS Report Number - PB96-916304
Title: Railroad Accident Report Collision of Washington Metropolitan Area Transit Authority Train T-111 with Standing Train at Shady Grove Passenger Station, Gaithersburg, Maryland January 6, 1996
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-96-03, *Adopted on* 09/04/1996
Order NTIS Report Number - PB96-916303
Title: Railroad Accident Report Collision Involving Two New York City Subway Trains on the Williamsburg Bridge in Brooklyn, New York June 5, 1995
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-96-01, *Adopted on* 03/19/1996
Order NTIS Report Number - PB96-916301
Title: Collision and Derailment of Two Subway Trains Metropolitan Transportation Authority New York City Transit in Brooklyn, New York, on February 9, 1995
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-93-03, *Adopted on* 12/07/1993
Order NTIS Report Number - PB93-916304
Title: Collision between Northern Indiana Commuter Transportation District Eastbound Train 7 and Westbound Train 12 Near Gary, Indiana, on January 18, 1993
APTA classification: Commuter Rail
Event Recorder? Probably

NTSB Report Number - RAR93-01*, *Adopted on* 04/27/1993
Order NTIS Report Number - PB93-916305
Title: Cleveland, Ohio--July 2, 1991
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR92-03*, *Adopted on* 10/27/1992
Order NTIS Report Number - PB92-916304
Title: New York, New York--August 28, 1991
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR92-01*, *Adopted on* 05/12/1992
Order NTIS Report Number - PB92-916302
Title: Chase, Maryland--April 12, 1991
APTA classification: Commuter Rail
Event Recorder? Probably

NTSB Report Number - RAR-92-01, *Adopted on* 02/25/1992
Order NTIS Report Number - PB92-916301
Title: Derailment and Collision of Amtrak Passenger Train 66 with MBTA Commuter Train 906 at Back Bay Station Boston, Massachusetts December 12, 1990
APTA classification: Commuter Rail
Event Recorder? Probably

NTSB Report Number - RAR-91-01, *Adopted on* 04/23/1991
Order NTIS Report Number - PB91-916301
Title: Derailment of Southeastern Pennsylvania Transportation Authority (SEPTA) Commuter Train 61 Philadelphia, Pennsylvania March 7, 1990
APTA classification: Commuter Rail
Event Recorder? Probably not

NTSB Report Number - RAR-90-01, *Adopted on* 03/13/1990
Order NTIS Report Number - PB90-916301
Title: Rear-end collision of two New York City Transit Authority Trains 103rd Street Station, New York, New York March 10, 1989
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-88-05, *Adopted on* 11/10/1988
Order NTIS Report Number - PB88-916306
Title: Rear-End Collision of Amtrak Massachusetts Bay Transportation Authority Commuter Trains, Boston, Massachusetts, November 12, 1987
APTA classification: Commuter Rail
Event Recorder? Probably not

NTSB Report Number - RAR-87-04, *Adopted on* 09/01/1987
Order NTIS Report Number - PB87-916304
Title: Collision and Derailment of Southeastern Pennsylvania Transportation Authority Single Car Train 167 69th Street Terminal Upper Darby, Pennsylvania August 23, 1986
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-87-02, *Adopted on* 04/28/1987
Order NTIS Report Number - PB87-916302
Title: Rear-End Collision Between Boston and Main Corporation Commuter Train No. 5324 and Consolidated Rail Corporation Train TV-14, Brighton, Massachusetts, May 7, 1986
APTA classification: Commuter rail
Event Recorder? Probably not

NTSB Report Number - RAR-87-01, *Adopted on* 04/14/1987
Order NTIS Report Number - PB87-916301
Title: Rear-End Collision of Two Greater Cleveland Regional Transit Authority Red Line Rapid Transit Trains near the 98th Street Station, Cleveland, Ohio July 10, 1985
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-86-03, *Adopted on* 08/05/1986
Order NTIS Report Number - PB86-916304
Title: Rear End Collision of Metro-Dade Transportation Administration Trains Nos. 172-171 and 141-142, Miami, Florida, June 26, 1985
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-86-01, *Adopted on* 03/27/1986
Order NTIS Report Number - PB86-916301
Title: Derailment of New York City Transit Authority Subway Train Dekalb Avenue Station Brooklyn, New York, May 15, 1985
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-85-13, *Adopted on* 10/21/1985
Order NTIS Report Number - PB85-916313
Title: Head-On Collision of Chicago, South Shore and South Bend Railroad Trains Nos. 123 and 218, Gary, Indiana, January 21, 1985
APTA classification: Commuter rail
Event Recorder? Probably not

NTSB Report Number - RAR-85-11, *Adopted on* 08/20/1985
Order NTIS Report Number - PB85-916311
Title: Rear End Collision of Two Chicago Transit Authority Trains near the Montrose Avenue Station, Chicago, Illinois, August 17, 1984
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-85-07, *Adopted on* 05/13/1985
Order NTIS Report Number - PB85-916307
Title: Derailment of New York City Transit Authority Subway Train in the Joralemon Street Tunnel, New York, New York, March 17, 1984
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-82-06, *Adopted on* 10/14/1982
Order NTIS Report Number - PB82-916306
Title: Derailment of Washington Metropolitan Area Transit Authority Train No. 410 at Smithsonian Interlocking. January 13, 1982
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RHR-82-03, *Adopted on* 10/19/1982
Order NTIS Report Number - PB82-917005
Title: Collision of a Southeastern Pennsylvania Transportation Authority Commuter Train with a Gasoline Truck, Southampton, Pennsylvania, January 2, 1982
APTA classification: Commuter rail
Event Recorder? Probably not

NTSB Report Number - RHR-82-02, *Adopted on* 10/14/1982
Order NTIS Report Number - PB82-917004
Title: Long Island Railroad, Commuter Train/Ford Van Collision, Mineola, New York, March 14, 1982
APTA classification: Commuter Rail
Event Recorder? Probably not

NTSB Report Number - RAR-82-02, *Adopted on* 05/14/1982
Order NTIS Report Number - PB82-916302
Title: Rear End Collision of New York City Transit Authority Subway Trains 142NL and 132NL, Brooklyn, New York, July 3, 1981
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-82-01, *Adopted on* 03/09/1982
Order NTIS Report Number - PB82-916301
Title: Head On Collision of Boston & Maine Corp Extra 1731 East & MBTA Train No. 570 on Former Boston & Maine Corp. Tracks, Beverly, Massachusetts, August 11, 1981
APTA classification: Commuter rail
Event Recorder? Probably not

NTSB Report Number - RAR-80-11, *Adopted on* 12/23/1980
Order NTIS Report Number - PB81-163230
Title: Rear End Collision of Septa Conrail Trains Nos. 406 and 472 on Conrail Track North Wales, Pennsylvania, July 17, 1980
APTA classification: Commuter rail
Event Recorder? Probably not

NTSB Report Number - RAR-79-08, *Adopted on* 08/02/1979
Order NTIS Report Number - PB-299196/AS
Title: Derailment of New York City Transit Authority Subway Train, New York, New York, December 12, 1978
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-79-05, *Adopted on* 07/19/1979
Order NTIS Report Number - PB-298905/AS
Title: Bay Area Rapid Transit Fire on Train No. 117 and Evacuation of Passengers While in the Transbay Tube, San Francisco, California, Jan. 17, 1979
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-78-05, *Adopted on* 08/17/1978
Order NTIS Report Number - PB-285705/AS
Title: Collision of Port Authority of Allegheny County Trolley Car No. 1790 and Bus No. 2413, Pittsburgh, Pennsylvania, February 10, 1978
APTA classification: Light Rail
Event Recorder? No

NTSB Report Number - RAR-78-02, *Adopted on* 02/09/1978
Order NTIS Report Number - PB-278191/AS
Title: Head On Collision of Two Greater Cleveland Regional Transit Authority Trains, Cleveland Ohio, July 8, 1977
APTA classification: Heavy rail
Event Recorder? No

NTSB Report Number - RAR-77-10, *Adopted on* 11/29/1977
Order NTIS Report Number - PB-277961/AS
Title: Rear End Collision of Two Chicago Transit Authority Trains, Chicago Illinois, February 4, 1977
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-77-05, *Adopted on* 08/04/1977
Order NTIS Report Number - PB-294648/AS
Title: Rear End Collision of Two Greater Cleveland Regional Transit Authority Trains, Cleveland, Ohio, Aug. 18, 1976
APTA classification: Heavy rail
Event Recorder? No

NTSB Report Number - RAR-76-09, *Adopted on* 07/08/1976
Order NTIS Report Number - PB-256693/AS
Title: Chicago Transit Authority Collision of Trains No. 104 and No. 315 at Addison Street Station, Chicago, Illinois, January 9, 1976
APTA classification: Heavy Rail
Event Recorder? No

NTSB Report Number - RAR-76-05, *Adopted on* 04/14/1976
Order NTIS Report Number - PB-253360/AS
Title: Rear End Collision of Three Massachusetts Bay Transportation Authority Trains, Boston, Massachusetts, August 1, 1975
APTA classification: Commuter rail
Event Recorder? Probably not

NTSB Report Number - RAR-75-08, *Adopted on* 07/16/1975
Order NTIS Report Number - PB82-171588
Title: Collision of Two Penn Central Commuter Trains at Botanical Garden Station, New York, New York, January 2, 1975
APTA classification: Heavy rail
Event Recorder? No

APPENDIX 3a

SELECTED ACCIDENT BACKGROUND SUMMARIES

SELECTED ACCIDENT BACKGROUND SUMMARIES

In conjunction with the primarily technical work for this report, the team selected a small sample of the accidents of interest listed in Appendix 3 for further examination. The following summaries were compiled from publicly available information, primarily newspapers, and show the media perspective of accident coverage. The italic text was taken from the NTSB report title. The summaries are supplemented by an "Event Recorder?" entry, added by the report team, to speculate on the applicability and usefulness of event recorder data, should it have been available. In nearly all cases, it would be useful to have event recorder data as hard supporting or backup evidence, even if the cause(s) was clear.

January 6, 1996 - *Collision of two Washington Metro trains on icy tracks*
1 fatality - the operator (RAR-97-01)

Description and probable cause: The engineer was unable to stop the train as it passed the platform at Shady Grove Station causing it to collide with a parked train. Despite the fact that the train was operating above system's speed limit (59 mph), the engineer was told by the Metro control center to continue automatic operations rather than switch to manual control. The NTSB report exposed numerous problems within the Washington Metropolitan Transit Authority. The direct cause of the accident was a system-wide defect in the computer-control of operations which for twenty years did not permit brakes to be set with enough pressure to consistently stop computer controlled trains on wet tracks. On the night of the accident, employees were following the orders of the Deputy General Manager who, without the knowledge of his superiors at Metro, had reversed Metro's 20-year policy of switching to manual operations in bad weather allowing operators more direct control of braking. The report also cited a management culture that discouraged workers from taking the initiative to challenge unsafe operating practices based on their own experience, knowledge and judgment. Workers feared they would lose their jobs if they countermanded orders, even if they were unsafe.

Event Recorder? Event recorder data would have been helpful in this accident, and was a specific recommendation of the NTSB report.

February 9, 1996 - *Ramming of two NJ Transit trains*
3 fatalities, two of them engineers and more than 150 injuries. (RAR-97-01)

Description and probable cause: The train ran a signal and rammed into a second train.

Event Recorder? These cars most likely were equipped with event recorders, although it was not mentioned in the news coverage. It would be discussed in the NTSB report.

February 16, 1996 - *Crash of an Amtrak train and a Maryland MARC commuter train outside Washington, DC.*
11 fatalities, three of them crew.

Description and probable cause: The MARC train was supposed to stop, but accelerated instead. Trains were going about 30 mph. Many victims died from smoke inhalation and were pounding on the windows to get out. Inadequate emergency doors were cited as contributing to fatalities. A young man had great difficulty opening window because the window stripping had been cemented back to the window to repair a leak. On some trains, to remove the window to escape a sign says: 'See placard at the end of the car'.

Event Recorder? Both trains were probably equipped with event recorders. Their contribution to finding the cause and preventing a recurrence would be described in the NTSB report.

New York June 5, 1995 - *Collision of two subway trains on Williamsburg Bridge.*
Motorman killed, more than 50 injuries.

Description: The train collided with a stopped train. The Motorman reportedly should have been able to see the signal and the stopped train, but was unable to stop.

Possible causes: Did the signals (which had reportedly been scheduled for repair for years) work properly? Did sudden onset of a physical problem (heart attack or stroke) prevent the motorman from seeing the stopped train?

Event Recorder? Event recorder data would have been helpful in this accident to determine the probable cause(s). This accident was a factor in NYCT's decision to purchase event recorders for future procurements of new cars.

February 9, 1995 - *Collision and derailment in Brooklyn*
No passengers were on board. An M train rammed into Manhattan bound B train.

Event Recorder? Event recorder data would have been helpful in this accident.

August 28, 1991 - *NYCT derailment in Brooklyn.*
5 fatalities, more than 200 injuries. (RAR-92-03)

Description and probable cause: Motorman convicted of 5 counts of manslaughter after operating train recklessly and at excessive speed under the influence of alcohol. The accident occurred underneath Union Square. The 10-car train slammed into a steel column after switching tracks on its approach to a station platform. The first car of the train was sheared in two. There was serious structural damage to the tunnel. Many of the injured suffered fractures and head injuries.

Event Recorder? Event recorder data would have been helpful in this accident, although the cause appeared to be clear.

March 7, 1990 *SEPTA six-car train derailment.*
3 fatalities, 94 injuries. (RAR-91-01)

Description and probable cause: Traction motors were the focus of NTSB investigation. Problems were found in primary support of 27 out of 76 traction motors inspected within 5 days after the accident. (There were 240 cars in the fleet and all were to be inspected.) A vertical support bolt held in place by a notched nut and cotter pin was secured too tightly, pushing the pin above the notches. The nut for the motor of the lead car was not found. The motorman tested positive for cocaine.

Event Recorder? Event recorder data would have been helpful in this accident, to add hard data to investigative work.

March 10, 1989 - *Rear end collision of two NY City Transit Authority Trains @ 103rd Street station.* (RAR-90-01)
This was reported as the most significant subway accident since 1981.
There were 50 injuries (8 of the injured were employees).

Description: Train rounded a curve, then rear-ended another train. Though the trains were derailed, they did not topple, but both were heavily damaged.

Possible cause: Possible causes included signal or brake problem or error by motorman.

Event Recorder? Event recorder data would have been helpful in this accident, to assist in determining the cause(s).

May 15, 1985 - *Derailment of a New York City Transit Authority subway train Dekalb Ave, Station Brooklyn*
21 injuries (including 2 train employees and two policemen), 2 fires

Description: Pulling out of the station, the 2nd car of an 8 car train jumped the track. The train progressed another 120 feet striking the electrified third rail and smashing into the track divider. This reportedly caused a short circuit that caused an explosion which in turn ignited a protective cover. When power was restored within the hour, it caused a second fire and explosion.

Possible cause: None noted.

Event Recorder? Event recorder data would have been helpful in this accident.

March 17, 1984 - *Derailment of 5 cars of a 10-car NYC Transit Authority subway train in the Joralemon St. Tunnel*
3-4 people treated at the scene, 9 others taken to hospital

Possible cause: None noted.

Event Recorder? Event recorder data would have been helpful in determining the cause of this accident

January 13, 1982 - *Derailment of Washington Metro Area Transit Authority Train No. 410* (RAR-82-06)
3 killed, at least 25 injured

Description and possible cause: (from the *NY Times*:)
"As the train bound for Maryland approached the Smithsonian Institute station from the north, its operator found he was still being switched to the opposite track even though two-track operations had been resumed. He called the systems central control...and was ordered to back up to before the crossover... A supervisor overseeing the manual switching because automatic switching was out of order, boarded the last car and took control of the back train...But at the far end, the last set of wheels had already passed the switches on the opposite track. The car was kept on the wrong track by an incorrect switch, officials said. Thus when the train moved, the last car was gradually turned sideways, spanning two sets of rails, and was crushed around a concrete pillar holding up the tunnel. 'There was enormous force because you had all the rest of the train pulling it forward' said [a spokesperson]... "

Officials at that point could not explain: why the switches were in the wrong position, why the controls failed requiring manual switching, if the operator of the crushed car, who was no longer controlling the train, could have done anything to prevent the disaster.

Event Recorder? Event recorder data would have been helpful in investigation of this accident.

January 2, 1982 - *Collision of single car with gasoline truck*
1 fatality (engineer), 4 injuries. (RHR-82-03)

Description and probable cause: Failure of railroad crossing signal which apparently did not work because the weight of the single car was not enough to maintain the continuous electric circuit required to operate the signal. It briefly triggered the light 1,990 ft. from the crossing, but was evidently not heavy enough to keep it activated.

With no signal light, the truck driver (Atlantic Richfield) drove across the track colliding with the train car. It overturned, exploded and crushed a nearby car. The incident started a three-alarm fire. The malfunction was probably related to a decision to use a single-car train on the 15-mile section of track to save money when SEPTA took over the run from Conrail. Conrail had been using two-car trains.

An NTSB spokesperson said there has been a history of single-car commuter trains failing to activate signals at crossings.

Event Recorder? Event recorder data might have been helpful in this accident, although grade crossing signals are not among the recorded signals.

July 3, 1981 - *Rear End Collision of 2 New York City Transit Authority Subway Trains*
Motorman dead, 35 injured

Possible cause: The failure of stop and go system (installed in 1918) caused a train to be halted. The motorman in another train failed to stop the train he was controlling and ploughed into the stopped train. A third train was successfully halted when power was turned off.

There was a subsequent dispute with a signal maintainer regarding alleged responsibility in the accident and his subsequent dismissal.

Event Recorder? Event recorder data would have been helpful in this accident

APPENDIX 4

VENDOR CONTACTS AND RESULTS

VENDOR CONTACTS

ATMS conducted a survey of event recorder manufacturers. The manufacturers contacted are listed in Table A.1. They included manufacturers of event recorders for applications in the rail, aviation, laboratory, and industrial fields. An initial review of the responses indicated that only thirteen (13) manufacturers make equipment that possibly may be applicable to the rapid rail industry. These include:

Allied Signal, Redmond WA
Bach-Simpson, London, Ontario
Flow Tech, Hunt Valley, MD
Keithly MetraByte, Taunton, MA
L3 Communications, Sarasota, FL
Moore Products, Spring House, PA
Optim Electronics, Germantown, MD
Pacific Instruments, Concord, CA
Peerless Instrument, Edgewood, NY
Pulse Electronics, Rockville, MD
Q-Tron USA, Inc., Alpharetta, GA
Quantum Engineering, Orange Park, FL
Telog Instruments, Victor, NY

Table A.2 provides selected information on these vendors, and their event recorders.

Table A.3 provides a comparison of the available information related to event recorder specifications of the various candidate vendors.

Table A.1 - Survey of Event Recorder Manufacturers

Manufacturer	Phone #	Cost	Applicable	Remarks
ABB Instrumentation, Inc	(716) 292-6050	n/a	n/a	Referred to Quantum Controls
Amteck, Inc	(847) 675-2500	n/a	n/a	Applicable to industry only.
Allied Signal	(425) 885-3711	$10,000 to $15,000	Yes	Aviation FDRs.
Aristoquatic	(800) 859-9289	n/a	n/a	Responded verbally after second call. Unable to meet any requirements of this type.
Bach-Simpson (WABCO)	(519) 452-3200	n/a	Yes	No cost information available. Additional information received by mail.
Chart Pool USA Inc	(219) 763-1541	n/a	n/a	
Cleveland Controls	(216) 398-0330	n/a	n/a	
Dancer Communications	(610) 543-8066	$495 to $1195	n/a	Data received. Not rugged. Limited channels. Designed for remote industrial monitoring.
Dia-Nelson	(609) 829-9441	n/a	n/a	Supplies only.
Dickson Company	(630) 543-3747	n/a	n/a	Single or duel channel only. Records on paper.
Electric Tachometer Corp	(215) 726-7723	n/a	n/a	Records on paper only, industry only
Eurotherm Chessell Corp	(215) 968-0660	n/a	n/a	Referred to Flow Tech
Flow Tech	(410) 666-3200	$3100 to $4800	Maybe	Applicable to industry only. Associated with Eurotherm Chessel
Gould	(703) 904-1860	n/a	n/a	Referred by IOtech, TRI Associates is local representative
Hathaway Process Instrumentation, Inc	(800) 537-2181	n/a	n/a	Applicable to industry only.
Hays Cleveland	(216) 398-4414	No	n/a	Local contact (Power and Heat) for pricing and technical information (804) 798-1318
Honeywell Limited	(416) 502-5200	n/a	n/a	Applicable to industry only.
Instrumentation Northwest	(800) 776-9355	n/a	n/a	Applicable to water uses only
IOtech	(216) 439-4091	n/a	n/a	Applicable to laboratory only
Keithly MetraByte	(800) 348-0033	No	Maybe	Has data collection technology (computer cards), would need additional components to make complete system
Keltron Corp	(617) 894-8710	n/a	n/a	Do not manufacture applicable product.
L3 Communications	371-0811 (941) 371-5505	$10,000 to $15,000	Yes	Aviation FDR manufacturer. Will build to specification.

Table A.1 - Survey of Event Recorder Manufacturers (cont'd)

Manufacturer	Phone #	Cost	Applicable	Remarks
Moore Products	(215) 646-7400 (804) 355-1640	$2600 to $5000	Maybe	Has data collection technology system but not designed for trains
Optim Electronics	(301) 428-7200	$9,000	Maybe	System designed for the laboratory or industrial environment.
Pacific Instruments	(510) 827-9010	$2,500 to $12,000	Maybe	Data received. Much appears to be for remote sensing not on-board sensing. Not hardened.
Penny & Giles Instrumentation	(512) 834-4388 (804) 672-6508	n/a	n/a	Mainly industrial. Does not do rugged or rail.
Peerless Instrument Co	(718) 592-3300	$6000 to $25,000	Yes	Received information.
Pulse Electronics	(301) 984-6642	$1,500 to $3,600	Yes	Fault monitoring equipment in place in the railroad industry.
Quantum Controls	(804) 379-2729	n/a	n/a	Referred to by ABB Instrumentation Records on paper only Not on trains, industry only
R C Electronics	(805) 685-7770	n/a	n/a	High speed industrial recording only. Not applicable to transit.
The Recorder Company	(830) 629-1400	n/a	n/a	Applicable to laboratory only.
Rexanne Product	(702) 294-2691	n/a	n/a	Representative for Dickson
Ronan Engineering Co	(818) 883-5211	n/a	n/a	Referred to Flow Tech
Rustruk Instruments	(401) 884-6800	n/a	n/a	Not in the business anymore.
Sprengnether Instrument	(314) 535-1682	n/a	n/a	Vibration monitoring only.
Telog Instruments Inc	(716) 742-3000		Maybe	No pricing information available.
TiPS Inc	(512) 863-3653	n/a	n/a	Applicable to industry only.
Vista Controls	(505) 662-2484	n/a	n/a	Applicable to laboratory only.
Western Graphtec	(800) 854-8385	n/a	n/a	Paper recording for industry only.
Westronics	(713) 348-1800	n/a	n/a	Applicable to industry only.
Yokogawa Corp of America	(800) 258-2552 (770) 253-7000	n/a	n/a	Applicable to industry only.

Table A.2 - Event Recorder Manufacturers

Manufacturer	Phone #	Cost	Hardened	Sufficient Analog & Digital Channels	Remarks
Allied Signal	(425) 885-3711	$10,000 to $15,000	Yes	Yes	Aviation FDR.
Bach-Simpson (WABCO)	(519) 452-3200	n/a	Yes	Yes	Has equipment in place in rail industry.
Flow Tech	(410) 666-3200	$3100 to $4800	No	Yes	Currently applicable to non-transportation industry only.
Keithly MetraByte	(800) 348-0033	n/a	No	Yes	Has data collection technology (computer cards), would need additional components to make complete system
L3 Communications	371-0811 (941) 371-5505	$10,000 to $15,000	Yes	Yes	Aviation FDR. Will build to specification.
Moore Products	(215) 646-7400 (804) 355-1640	$2600 to $5000	No	Yes	Has data collection technology system but not designed for trains
Optim Electronics	(301) 428-7200	$9,000	No	Yes	System appears to be designed for the laboratory or industrial environment.
Pacific Instruments	(510) 827-9010	$2,500 to $12,000	Yes	Yes	Appears to be for remote sensing, not on-board sensing.
Peerless Instrument Co	(718) 592-3300	$6000 to $25,000	Yes	Yes	Has equipment in place in rail industry.
Pulse Electronics	(301) 984-6642	$1,500 to $3,600	Yes	Yes	Fault monitoring equipment in place in the railroad industry.
Q-Tron USA, Inc.	(770) 410-1200	$2,600 +	Yes	Yes	Railroad Electronics Division
Quantum Engineering	(904) 278-2500	$3,700	Yes	Yes	Has equipment in place in rail industry. Price includes sensors.
Telog Instruments Inc	(716) 742-3000	n/a	No	Yes	Designed mainly for industry.

Table A.3 - Event Recorder Specifications

Manufacturer	Model	Number of Digital Channels	Number of Analog Channels	Number of Output Channels	Sampling Rate	Memory Capacity	Comm Interface	Cost
Allied Signal	ED-55			1		25 Hour Capacity	RS-422	$10,000 to $15,000
Bach-Simpson (WABCO)	ELP 300	48	16	8	Up to 5 KHz	Up to 4 MB	RS-232 RS-485	n/a
Flow Tech	4100G	0	Up to 12	1		Up to 10 MB	RS-485	$3100 to $4800
Keithly MetraByte	Datataker Series 500 and 600	Up to 84	Up to 50	Up to 44	Up to 300 KHz	Up to 1 MB	RS-232 RS-423	n/a
L3 Communications	FA2100			1	n/a	25 Hour Capacity	RS422	$10,000 to $15,000
Moore Products	Series 363	0	24	24	2 Hz	Up to 1 MB	n/a	$2600 to $5000
Optim Electronics	Megadac 3415AC	0	Up to 300	Up to 128	Up to 250 KHz	Up to 4 MB	RS-232; RS-422; RS-485; IEEE-488.1	$9,000
Pacific Instruments	Series 5000	Up to 30	Up to 30	1	Up to 1 MHz	Up to I MB	IEEE-488.1	$2,500 to $12,000
Peerless Instrument Co	1230	25	9	1	1 Hz	4 MB	RS-232	$6000 to $25,000
Pulse Electronics	M-Series	Up to 72	8	1	1 Hz	Store up to 10,000 data items	RS-232 RS-422 RS-485	$1,500 to $3,600
Q-Tron, USA Inc.	DataCord 5000 Series	Up to 72	Up to 30	Up to 10	10 Hz	Up to 2 MB	RS-232 RS-422 RS-485	Starting at $2,600
Quantum Engineering	Q1036	120	20	1	1 Hz	48 Hour Capacity	RS-232	$3,700
Telog Instruments Inc.	R-3314	6	8	1	1 Hz	512 KB	RS-232	n/a